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Upper Ordovician Ecology of the Central Appalachians

Peter William Bretsky, Jr.

Bulletin 34

PEABODY MUSEUM
OF NATURAL HISTORY
YALE UNIVERSITY

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Upper Ordovician Ecology of the Central Appalachians

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UPPER ORDOVICIAN ECOLOGY OF THE CENTRAL APPALACHIANS

By Peter William Bretsky, Jr.

ABSTRACT

The upper Reedsville Formation and portions of equivalent Martinsburg strata (Upper Ordovician) in the central Appalachians provide one of the earliest known examples of a prolific clastic-facies invertebrate fauna with a distinctly modern aspect. This study is a paleoecological investigation of the faunal communities comprising this invertebrate assemblage (especially the classical *Orthorhynchula* Zone of Bassler), and their geographic variation along a 600-mile-long Late Ordovician shoreline. In addition a systematic description of the invertebrates collected during the present investigation was undertaken.

About 5,100 specimens from 164 fossiliferous central Appalachian exposures provided the basis for the description of 31 species (and/or genera) that are most common in this Late Ordovician assemblage. Numerically dominant taxa are the trepostomatous bryozoans, brachiopods, gastropods and bivalve molluscs. The distributional pattern of species within each of these four major taxonomic groups outlines twelve faunal provinces, which are taxonomically distinct enough to aid in more detailed autecological interpretations of the Late Ordovician species.

The zoogeographic and autecological data are combined into a synecological review of the main environmental settings and associated faunas. Those species which show a high degree of affinity and a pronounced tendency to recur together throughout the Upper Ordovician strata are called communities. There are three communities which are further subdivided into seven multi-species populations that are more restricted geographically and stratigraphically, and presumably reflect more localized environmental conditions. The communities and populations are:

(1) *Sowerbyella–Onniella* Community (Strophomenid and Orthid–Crinoid Populations): lived on muddy silt bottoms of the outer sublittoral from central Pennsylvania to north-central Virginia; abundant strophomenid (*Sowerbyella, Rafinesquina*) and dalmanellid (*Onniella*) brachiopods, pleurotomariid gastropods [*Loxoplocus* (*Lophospira*) and *Ruedemannia*], nuculoid (*Ctenodonta*?, *Praenucula*) and actinodontoid (*Lyrodesma*) bivalves, crinoids and lesser numbers of trilobites.

(2) *Orthorhynchula–Ambonychia* Community (Linguloid, Rhynchonellid and Modiolopsid Populations): lived on sand-silt bottoms of the inner sublittoral and intertidal from south-central Pennsylvania to south-central Virginia; abundant rhyn-

chonellid (*Orthorhynchula*) and linguloid (*Lingula?*) brachiopods, bellerophontid gastropods (*Plectonotus?*, *Bucania*), modiomorphid (*Modiolopsis, Ischyrodonta*), ambonychiid (*Ambonychia*) and nuculoid (*Tancrediopsis*) bivalves.

(3) *Zygospira–Hebertella* Community (Spiriferid and Orthid Populations); lived on mud and silty mud bottoms of the inner and outer sublittoral from southwestern Virginia to northern Tennessee; abundant spiriferid (*Zygospira*) and orthid (*Hebertella*) brachiopods, pterioid bivalves [*Pterinea* (*Caritodens*)], murchisoniid gastropods (*Murchisonia*), and trepostomatous bryozoans (*Hallopora, Dekayia, Monticulipora, Amplexopora, Batostomella*).

This study has shown that the Upper Ordovician rocks in the central Appalachians enclose a shallow water marine fauna that exhibits not only a distinctive onshore to offshore distributional pattern but also a longshore one. Nearshore environments are commonly dominated by bellerophontid gastropods, nuculoid and modiomorphid bivalve molluscs, linguloid and rhynchonellid brachiopods, whereas the offshore regimes are composed predominantly of orthid, strophomenid and spiriferid brachiopods, crinoids and trepostomatous bryozoans. This general distributional pattern is modified significantly by the position of the major source area in central Pennsylvania as the characteristic offshore brachiopods and bryozoans come to occupy more nearshore environments in southwestern Virginia and northern Tennessee.

ZUSAMMENFASSUNG

Die obere Reedsville Formation und Teile der äquivalenten Martinsburg Strata (Obere Ordovizian) in den Zentral Appalachen liefern eine der frühesten bekannten Beispiele einer reichen "clastic-facies" wirbellosen Fauna mit einem ausgeprägten modernen Aussehen. Dieses Studium ist eine paläeökologische Erforschung der Tiergemeinschaften, die diese wirbellose Sammlung (hauptsächlich die klassische *Orthorhynchula* Zone von Bassler) und seiner geographischen Verschiedenheit entlang einer 600-Meilen späten Ordovizian Küste umfassen. Zusätzlich wurde eine systematische Beschreibung von wirbellosen Tieren unternommen, die während der vorliegenden Untersuchung gesammelt wurde.

Ungefähr 5, 100 Proben von 164 fossilienführenden Aufschlüssen in den Zentral Appalachen liefern die Basis für die Beschreibung von 31 Arten (und/oder Gattungen) die am häufigsten in dieser späten Ordovician Sammlung auftauchen. Zahlenmäzige vorherrschende Taxa sind die trepostomatischen Bryozoen, Brachiopoden, Gastropoden und Muscheln. Die Verbreitungsformen der Arten innerhalb jeder dieser vier Hauptgliederungen begrenzen zwölf Tiergebiete. Diese Tiergebiete sind genügend taxonomisch verschieden um ausfuhrlichere autökologische Darstellungen der späten Ordovizian Arten zuzufügen.

Die zoogeographische und autökologische Angaben sind mit einem Uberblick über die hauptsächlichen Milieus und den dazugehörigen Tierwelten verbunden. Die Arten welche einen hohen Grad von Verbindungsfähigkeit zeigen und eine ausgesprochene Tendenz haben zusammen in der Oberen Ordovizian Strata aufzutreten, werden als Gemeinschaften bezeichnet. Es gibt drei Gemeinschaften welche man noch in sieben "multi-species" Populationen welche geographisch und stratigraphisch mehr begrenzt sind und voraussichtlich mehr örtliche Umgebungs-bedingungen aufzeigen. Die Gemeinschaften und Population sind:

(1) *Sowerbyella – Onniella* Gemeinschaft (Strophomenid und Orthid-Krinoid Population): lebte auf schlammigem Böden der äusseren Sublittoralzone von Zentral Pennsylvania bis Nord-Zentral Virginia; zahlreiche strophomenid (*Sowerbyella*, *Rafinesquina*) und dalmanellid (*Onniella*) Brachiopoden, pleurotomariid Gastropoden [*Loxoplocus* (*Lophospira*)] und *Ruedemannia*, nuculoid (*Ctenodonta*?, *Praenucula*) und actinodontoid (*Lyrodesma*) Muscheln, Krinoiden und weniger Trilobiten.

(2) *Orthorhynchula – Ambonychia* Gemeinschaft (Linguloid, Rhynchonellid und Modiolopsid Population): lebte auf sand-schlammigen Boden der inneren Sublittoralzone und Zwischengezeitenzone von Süd-Zentral Pennsylvania bis Süd-Zentral Virginia; zahlreiche rhynchonellid (*Orthorhynchula*) und linguloid (*Lingula*?) Brachiopoden, bellerophontid Gastropoden (*Plectonotus*?, *Bucania*), modiomorphid (*Modiolopsis*, *Ischyrodonta*), ambonychiid (*Ambonychia*) und nuculoid (*Tancrediopsis*) Muscheln.

(3) *Zygospira – Hebertella* Gemeinschaft (Spiriferid und Orthid Population): lebte auf schlammigem Boden der inneren und äusseren Sublittoralzone von

Südwest Virginia bis Nord Tennessee; zahlreiche spiriferid (*Zygospira*) und orthid (*Hebertella*) Brachiopoden, pterioid Muscheln [*Pterinea* (*Caritodens*)], murchisoniid Gastropoden (*Murchisonia*), und trepostomatischen Bryozoen (*Hallopora, Dekayia, Monticulipora, Amplexopora, Batostomella*).

Diese Studium hat zezeigt, dass die obere Ordovizian Steine in den Zentral Appalachen eine Flachwasser marine Fauna enthalten, welche nicht nur eine ausgeprägte nahe an der Küste gelegene bis Küste eutfernte Verteilungsform haben, aber auch eine Küste-parallel Form. Nahe an der Küste gelegene Gebiete sind normalerweise beherrscht von bellerophontid Gastropoden, nuculoid und modiomorphid Muscheln, linguloid und rhynchonellid Brachiopoden, während die von der Küste entfernten Gruppen sind vorherrschend von orthid, strophomenid und spiriferid Brachiopoden, Krinoiden und trepostomatsche Bryozoen zusammengesetzt. Diese allgemeine Verteilungsform is bedeutend verändert von der Lage der Hauptlieferungsgebiete in Zentral Pennsylvania als die bezeichnenden vom Lande eutfernte Brachiopoden und Bryozoen begannen näher an der Küste gelegenen Gebiete in Sudwest Virginia und Nord Tennessee zu besetzen.

РЕЗЮМЕ

Верхняя часть формации Ридсвил (Reedsville) и некоторые части соответствующих этой верхней части по возрасту Мартинсбергских (Martinsburg) слоев (верхний ордовик), в центральных Аппалачах, содержат один из самых ранних примеров богатой фауны беспозвоночных кластической фации и отчетливо современного вида. Предлагаемая работа — результат палеоэкологического исследования фаунальных обществ, включающих эту ассоциацию беспозвоночных (в особенности, классическую зону с *Orthorhynchula* Басслера) и их географических изменений вдоль поздно-ордовикского берега, длиной в 1000 километров. Кроме того, беспозвоночные, собранные в течение наших исследований, систематически описаны.

Около 5100 экземпляров из 164 фоссилоносных выходов в центральных Аппалачах служили базисом для описания 31 самых распространенных в этой поздно ордовикской ассоциации видов и родов. Численно преобладающие таксоны — трепостоматные мшанки, брахиоподы, брюхоногие и двустворчатые моллюски. Распределения видов этих четырех таксономических групп определяют двенадцать фаунальных провинций, которые таксономически различаются в достаточной степени, чтобы оказались полезным для детальной автоэкологической интерпретации поздно ордовикских видов.

Зоогеографические и автоэкологические данные объединены в синэкологический обзор главных типов сред и ассоциированных с ними фаун. Группы видов, показывающих в высокой степени склонность проявляться вместе снова и снова в течение отложения верхне-ордовикских слоев, названы нами обществами. Имеются три общества. Они подразделены в семь многовидных популяций, более ограниченных географически и стратиграфически, и предположительно, соответствующих более локализованным условиям среды. Общества и популяции:

(1) Общество *Sowerbyella-Onniella* (строфоменидная и ортидо-криноидная популяция), которое жило на илистом дне внешнего сублитторала, от центральной Пенсильвании до северо-центральной Вирджинии: обильные строфоменидные *(Sowerbuella, Rafinesquina)* и далманеллидные *(Onniella)* брахиоподы, плевротомариидные брюхоногие [*Loxoplocus (Loxospira)*] и *Ruedemannia*, нукулоидные *(Ctenodonta?, Praenucula)* и актинодонтоидные *(Lyrodesma)* двустворчатые, криноиды и менее число трилобитов.

(2) Общество *Orthorhynchula-Ambonychia* (лингулоидная, ринхонеллидная и модиолопсидная популяция), которое жило на песчано-иловых днах внутреннего сублиттораля и зоны прилива, от юго-центральной Пенсильвании до юго-центральной Вирджинии: обильные ринхонеллидные *(Orthorhynchula)* и лингулоидные *(Lingula ?)* брахиоподы, беллерофонтидные брюхоногие *(Plectonotus ?, Bucania)*, модиоморфидные *(Modiolopsis, Ischyrodonta)*, амбонихиидные *(Ambonychia)* и нукулоидные *(Tancrediopsis)* двустворчатые.

(3) Общество *Zygospira-Hebertella* (спириферидная и ортидная популяция), которое жило на иловых днах внутреннего и внешнего сублиттораля, от юго-восточной Вирджинии до северного Теннесси: обильные спириферидные *(Zygospira)* и ортидные *(Hebertella)* брахиоподы, птериоидные двустворчатые [*Pterinea (Caritodens)*], мурчисониидные брюхоногие *(Murchisonia)* и трепостоматные мшанки *(Hallopora, Dekayia, Monticulipora, Amplexopora, Batostomella)*.

Наши исследования показали, что верхне-ордовикские породы в центральных Аппалачах заключают мелководную фауну, обнаруживающую характерное распределение, которое варьирует не только с удалением от берега, а тоже с смещением вдоль берега. В прибрежных средах обычно доминируют беллерофонтидные брюхоногие, нукулоидные и модиоморфидные двустворчатые моллюски, лингулоидные и ринхонеллидные брахиоподы, тогда как у режимов открытого моря преобладают ортидные, строфоменидные и спириферидные брахиоподы, криноиды и трепостоматные мшанки. Это общее распределение, замечаемое в главной области собирания в центральной Пенсильвании, значительно изменяется вдоль древнего берега: характерные брахиоподы и мшанки открытого моря находятся в средах, близких берегу, в юго-западной Вирджинии и северном Теннесси.

INTRODUCTION

The present work is a paleoecologic study and systematic redescription of the invertebrate faunas, especially the *Orthorhynchula* Zone fauna, from the fossiliferous beds at the top of the Reedsville Formation (Upper Ordovician) in the central Appalachian Valley and Ridge Province. Also included in this study are data from the Shochary Sandstone Member of the Martinsburg Formation in the Great Valley of eastern Pennsylvania (see Bretsky et al., 1969). The investigation was undertaken because these Lower Paleozoic rocks preserve the first major incursion of a clastic-facies invertebrate fauna in Paleozoic rocks of the Appalachians. Earlier Paleozoic faunas in the Appalachian region occur predominantly in carbonate rocks. The fossil assemblage is especially significant because it is the earliest to contain recognizable nearshore faunas of distinctly modern aspect.

Only a few workers on Paleozoic invertebrates have stressed the ecology of clastic-facies faunas. The preliminary studies of Ziegler (1965) in the British Silurian and of Sutton et al. (1966) in the New York Devonian are illuminating contributions, as are the investigations of Elias (1937), Johnson (1962) and Stevens (1966), principally in the Mid-Continent Pennsylvanian and Permian.

This investigation is concerned with the faunal associations and their zoogeographic variations along the Reedsville-Martinsburg outcrop belt that extends from northeastern Pennsylvania to northern Tennessee (Fig. 1). It includes Bassler's (1919) *Orthorhynchula* Bed or Zone. The zone was named for an abundant species of rhynchonellid brachiopod, *Orthorhynchula linneyi* (James), which Butts (1940, p. 208) had found "universally present and abundant in the *Orthorhynchula* Bed from central Pennsylvania to the south end of Clinch Mountain . . . Tennessee." The zone, however, is characterized by inarticulate as well as rhynchonellid brachiopods, gastropods, bivalve molluscs and trepostomatous bryozoans, not all of which are found at every exposure of the "zone" in the central Appalachians. Furthermore, *Orthorhynchula linneyi* occurs in Middle and Upper Ordovician rocks in central Tennessee and Kentucky (Wilson, 1949; Foerste, 1910), but earlier investigators stressed the broad biostratigraphic importance of the *Orthorhynchula* Zone fauna specifically along the Appalachian Valley and Ridge Province. The *Orthorhynchula* Zone has been interpreted as a marker bed that has little or no time significance, but rather is integrally related to a particular lithology (Woodward, 1951, p. 335 ff.; Butts, 1945, p. 5). Butts (1940, p. 208) states that the rock type is a "slightly calcareous, generally fine-grained . . . thick or massively bedded sandstone". A few pages later, however, he (1940, p. 217) says that the *Orthorhynchula* faunas were found preserved in a variety of limestones, shales and sandstones; therefore, the zone may also have been viewed as a local range zone or teilzone, although this interpretation has never been stressed in the earlier literature. Also the paleogeographic relationships of these zonal faunal elements to other abundant Upper Ordovician faunas in the Appalachians were never clearly defined, and because I have emphasized the environmental aspects of this fauna, I would thus prefer to view the *Orthorhynchula* Zone as a fossil community zone (see Berry, 1966, p. 1492).

The stratigraphic range of this zone at the top of the Reedsville Formation was determined by the maximum thickness of the beds containing the *Orthorhynchula* assemblage in central Virginia, south-central Pennsylvania and east-central West Virginia (Fig. 2); this normally amounted to about 100 feet or less. The replacement of many of the typical *Orthorhynchula* Zone fossils in this stratigraphic interval by other species and fossil assemblages was determined by a study of closely spaced sections along the out-crop belt from northeastern Pennsylvania to northern Tennessee.

State and regional geologic maps provided the stratigraphic base for the study. The surveys of Butts (1933), Cloos (1941), Rodgers (1953), Stose (1932), Gray (1960) and Calver (1963) were supplemented by a number of quadrangle reports dealing with north-central Virginia and southern Pennsylvania. Other central Appalachian literature was surveyed for reference to any previously known exposures of fossiliferous Upper Ordovician rocks. Many of these previously published stratigraphic sections were adequate only in so far as they gave some indication of the overall thickness of the fossiliferous upper Reedsville strata. The total number of localities visited amounted to more than 200, but fossils were present and collected from only 164. About 5,100 specimens from these 164 fossiliferous exposures provided the basis for the description of 31 species (and/or genera) that are incorporated into a systematics section at the end of this paper. At over 90 localities fossils were collected from well-defined stratigraphic horizons, approximately 35 additional localities served, to some degree, as accurate stratigraphic control; the remaining 40 localities were of more limited value, for the exact order and thickness of the various rock units were not clear at these exposures. In this study data were gathered concerning bedding features, lithologic type and relative abundance of species. Tentative field identifications of both rock and fossil materials were checked in the laboratory.

Grain size of terrigenous material accords with the Wentworth grade scale (1922). Bedding thickness is classified after McKee and Weir (1953) and Ingram (1954). The textural classification of detrital rocks generally follows the one presented by Krumbein and Sloss (1963, p. 153). Bathymetric terms are used in the reconstruction of these Paleozoic environmental settings, and the reader is cautioned to view these only as reasonable estimates. Hedgpeth (1957, fig. 1) and Valentine (1961, fig. 2) diagram and briefly discuss the use of the terms, "littoral, and inner and outer sublittoral", all of which refer to the shelf environments in water of less than 200 meters depth. The synecological terms frequently used in this paper are:

Community—An association of recurring species that are numerically dominant and show some relationship to a physical environment or environmental parameter. This definition applies to the organism and habitat communities of Newell et al. (1959) and agrees with the definitions of marine level-bottom communities given by most marine biologists (see Speden, 1966).

Population—All the organisms presumably inhabiting an area during any given

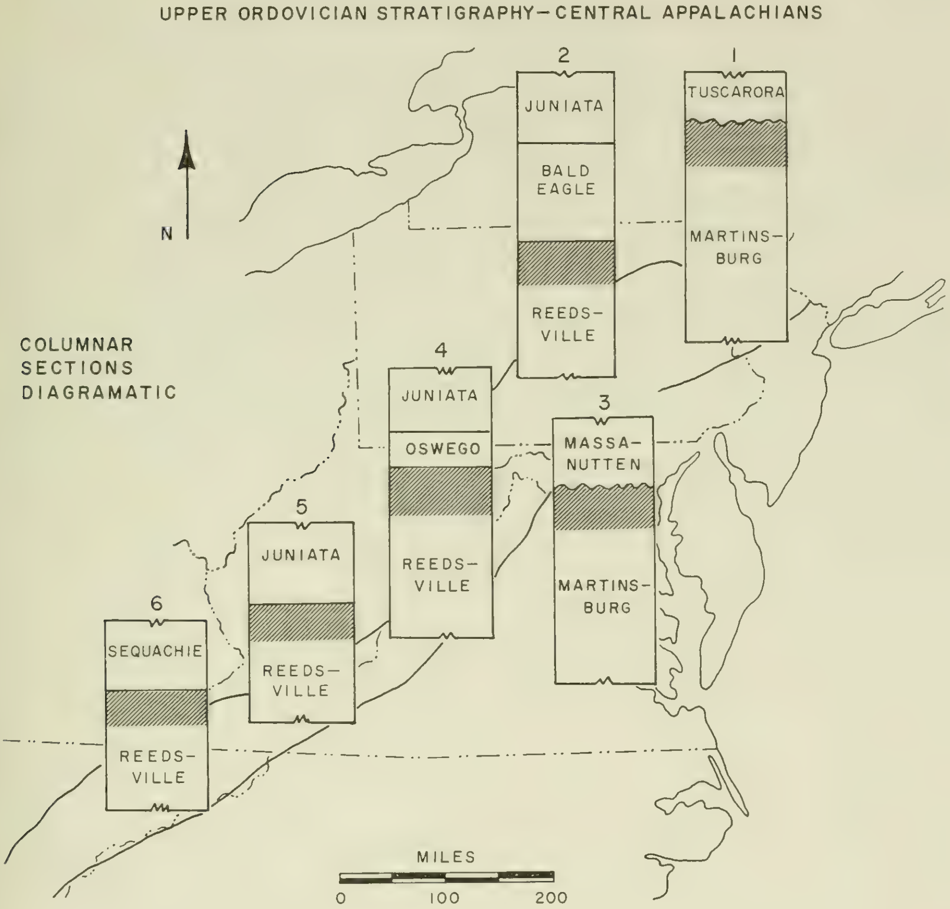
UPPER ORDOVICIAN STRATIGRAPHY—CENTRAL APPALACHIANS
N
COLUMNAR SECTIONS DIAGRAMATIC
1
TUSCARORA
MARTINSBURG
2
JUNIATA
BALD EAGLE
REEDSVILLE
3
MASSANUTTEN
MARTINSBURG
4
JUNIATA
OSWEGO
REEDSVILLE
5
JUNIATA
REEDSVILLE
6
SEQUACHIE
REEDSVILLE
MILES
0
100
200

FIG. 2. Schematic columnar sections, Upper Ordovician strata north-central Appalachians. Data primarily from Twenhofel et al. 1954. Cross-hatched area of each column indicates fossiliferous rocks studied in this report. Outline of Valley and Ridge Province shown as solid lines from Pennsylvania into Tennessee.

Location of sections:

1. Eastern Pennsylvania, Shochary Ridge
2. South-central Pennsylvania
3. Northern Virginia, Massanutten Mountain
4. Eastern West Virginia and west-central Virginia
5. South-central Virginia
6. Northern Tennessee and southwestern Virginia

time—in this case, all those inhabiting some part of the central Appalachians during some interval of the Late Ordovician. As defined by Clarke (1954, p. 333), these may be single-species or multi-species populations. Communities and populations are similarly defined but the latter are more restricted geographically and stratigraphically.

Faunal Province—A geographic region in which a particular systematically segregated taxonomic group maintains a characteristic specific composition (see Valentine, 1961, p. 341, and A.G.I. Glossary of Geology, 1960, p. 106). An example is the central Appalachian Late Ordovician brachiopod fauna, which consists of three distinct faunal provinces, each one dominated by a particular assemblage of brachiopod species.

ACKNOWLEDGMENTS

I am indebted to many individuals for discussion, suggestions and advice during the course of this investigation. Those most actively involved were Dr. Richard Boardman of the U. S. National Museum; Drs. John Pojeta and Ellis Yochelson of the U. S. Geological Survey; and Drs. Karl Waage and Donald C. Rhoads of Yale University. Because I had expressed an interest in studying the zoogeography and ecology of an Early Palezoic fossil assemblage, Dr. A. Lee McAlester suggested the possibility of applying a synecological approach to the classical "*Orthorhynchula* Zone" faunas in the central Appalachians. I sincerely appreciate his continual support and encouragement throughout the investigation.

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STRATIGRAPHIC FRAMEWORK

The paleoecologic reconstruction of the Late Ordovician invertebrate faunas in the central Appalachians involves only those fossiliferous beds at the top of the Reedsville and Martinsburg Formations, specifically the faunas of the classical *Orthorhynchula* Zone or Bed of Bassler (1919). Stratigraphic and geographic relationships are presented in Figure 2 (data primarily from Twenhofel et al., 1954, also see Bretsky, 1969).

The nomenclatural problems surrounding the use of the terms Reedsville Formation, Reedsville lithofacies, Martinsburg Formation and Martinsburg lithofacies are reviewed by McBride (1960, 1962). Ulrich (1911, pl. 27; 1913, p. 644) assigned the term Reedsville Formulation to the fossiliferous Upper Ordovician sandstones and shales in the central Pennsylvania Valley and Ridge Province, to differentiate them from the relatively unfossiliferous Martinsburg Formulation in the Great Valley of eastern Pennsylvania. Figure 3 (modified from Ulrich) presents the correlation of these rock units. Ulrich excluded from the Reedsville some of the underlying Trenton

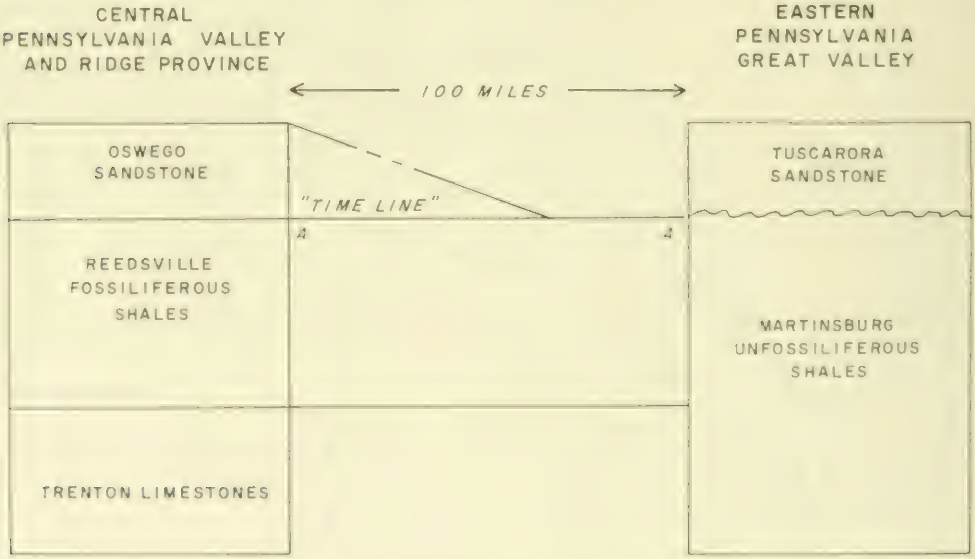

CENTRAL
PENNSYLVANIA VALLEY
AND RIDGE PROVINCE
EASTERN
PENNSYLVANIA
GREAT VALLEY
100 MILES
OSWEGO
SANDSTONE
"TIME LINE"
TUSCARORA
SANDSTONE
A
A'
REEDSVILLE
FOSSILIFEROUS
SHALES
MARTINSBURG
UNFOSSILIFEROUS
SHALES
TRENTON LIMESTONES

FIG. 3. Correlation of the Upper Ordovician strata in Pennsylvania after Ulrich (1911). The distance between the generalized columnar sections is approximate. The Martinsburg Formation is not totally unfossiliferous (e.g., Shochary Ridge Sandstone Member) but in comparison with the Reedsville Formation it has been referred to commonly as an unfossiliferous shale. Line A-A' connects lithologic units of supposed equivalent age.

limestones which he believed to be equivalent in age to the lowest units of the Martinsburg Formation. The definition of the Reedsville-Martinsburg boundary has, however, lacked precision since Ulrich's differentiation.

McBride (1960, p. 26–27) has interpreted the Reedsville and Martinsburg rocks as lithofacies of each other, with an axis of intersection between these two lithofacies along the western edge of the Great Valley in Pennsylvania and Maryland (Fig. 4). According to his scheme, much of the Martinsburg "barren" shales had been deposited prior to the deposition of the Reedsville fossiliferous shales. In accepting McBride's interpretation I have considered only the Shochary Sandstone beds in eastern Pennsylvania and the fossiliferous siltstones and shales underlying the Massanutten Sandstone in north-central Virginia as part of the Martinsburg Formation. Woodward (1951, p. 332–376) and McBride (1960, p. 12–24, esp. table 1, p. 14) have presented detailed historical reviews of the Reedsville-Martinsburg nomenclatural problems in the central Appalachians, to which the reader is referred.

The fossiliferous beds at the top of the Reedsville and Martinsburg Formations have no formal rock-stratigraphic designation in the literature, although they constitute all or part of a generally recognized upper member of the Reedsville (Horowitz, 1965; Rader and Ryan, 1965; Pierce, 1966; and Butts, 1945). Lithologies in which the fossils occur vary along the outcrop belt, but rock types exhibit an overall north-south trend. Thick to massively bedded sandstones are common in the north and grade into thin- to medium-bedded siltstones, shales and limestones toward the

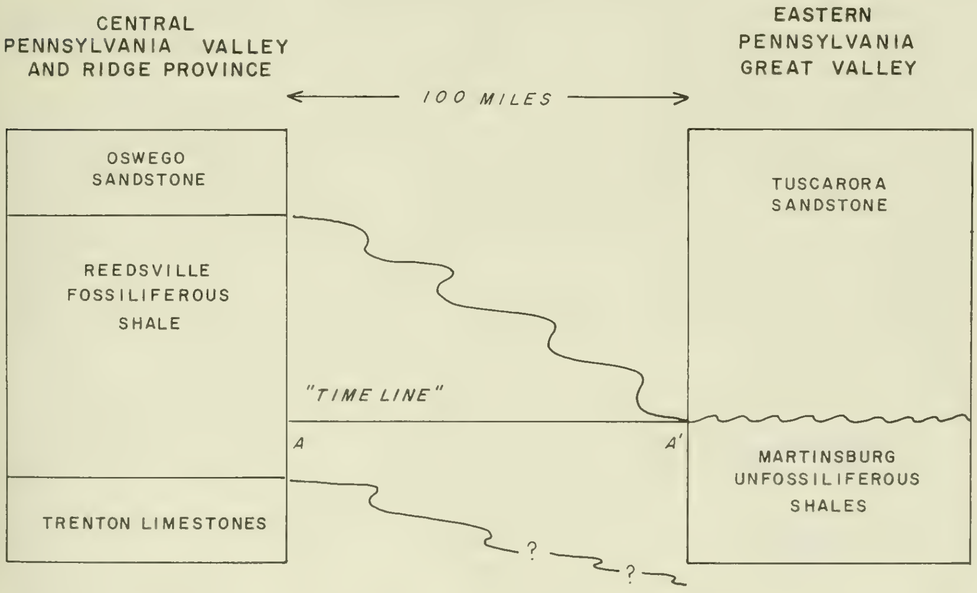


FIG. 4. Correlation of the Upper Ordovician strata in Pennsylvania after McBride (1960). McBride's interpretation emphasizes the concept of lithofacies migration throughout a significant period of geologic time. It should be noted that this interpretation is based on the overall Upper Ordovician stratigraphic and sedimentological setting and has not included the fossil record, although a sparse fauna exists in the Shochary Ridge Sandstone Member of the Martinsburg Formation. Line A-A′ connects lithologic units of supposed equivalent age.

south. Figure 5 shows the relative proportions and stratigraphic and geographic distribution of the various lithologies in the central Appalachians. The lower contact of the abundantly fossiliferous strata is commonly gradational into the thinner bedded, finer grained and sparcely fossiliferous rocks, whereas the upper contact, based on bedding, lithology and color characteristics is normally much more abrupt (see Horowitz, 1965, p. 9–22, for definition of the lower contact on slight changes in bedding thickness); the fossiliferous beds of the upper Reedsville and Martinsburg are overlain by Oswego (= Bald Eagle) quartzitic sandstones in central Pennsylvania and eastern West Virginia (Fig. 7), Juniata red shales and sandstones from east-central Pennsylvania to Tennessee, Sequatchie red limestones in Tennessee, and Tuscarora (Massanutten) quartzitic sandstones in eastern Pennsylvania and north-central Virginia (Fig. 2). Some interbedding of the upper fossiliferous Reedsville and the Oswego and Juniata Formations occurs over a few tens of feet, but the upper contact normally appears quite sharp, although it is probably unconformable only in portions of eastern and central Pennsylvania and north-central Virginia (Figs. 2 and 5).

Prior to my study, the *Orthorhynchula* Zone faunas were viewed as a lithologically controlled biofacies (Butts, 1945, p. 5; Woodward, 1951, p. 335 ff.), or possibly a local range zone or teilzone (Butts, 1940, p. 217). This latter interpretation is based on the fact that the characteristic fauna of the *Orthorhynchula* Zone, mainly abundant rhynchonellid and linguloid brachiopods and some bivalve molluscs, have been found at the same stratigraphic position (i.e., near or at the top of the Reedsville or Martinsburg) in thin-bedded limestones, argillaceous limestones and thick-bedded quartz sandstones. This may lend some credence to an interpretation of the *Orthorhynchula* Zone faunas as significant time-stratigraphic markers in the central Appalachian Valley and Ridge Province.

The fauna of the central Appalachian *Orthorhynchula* Zone is typified not only by large numbers of the rhynchonellid *Orthorhynchula linneyi*, but also by abundant linguloid brachiopods, bellerophontid gastropods, and modiomorphid, ambonychiid and nuculoid bivalve molluscs. Other fossiliferous strata at the top of the Reedsville and Martinsburg include abundant species of orthid, strophomenid and atrypid brachiopods, pleurotomariacean gastropods, trepostomatous bryozoans, crinoids and occasionally abundant trilobites (see Fig. 7 which diagrams a composite columnar section typical of eastern West Virginia and south-central Pennsylvania, showing bedding features and lithologies as well as major faunal components).

I have interpreted the *Orthorhynchula* Zone faunas as containing two fossil community zones (see Berry, 1966, p. 1492) — the *Orthorhynchula–Ambonychia* Community in southern Pennsylvania and central Virginia, and the *Zygospira–Hebertella* Community in southwestern Virginia and northern Tennessee. The species in the fossiliferous strata comprising the third community defined in this study, the *Sowerbyella–Onniella* Community, were never considered to be part of the *Orthorhynchula* Zone by earlier workers, since this community contains no large rhynchonellid or linguloid brachiopods. The fossiliferous strata comprising the *Orthorhynchula–Ambonychia* and *Sowerbyella–Onniella* Communities are, however, occasionally interbedded in south-central Pennsylvania and northern Virginia (Fig. 6), although the faunas are rarely mixed. My interpretations, of course, do not negate the time-stratigraphic significance of the zonal faunas, but rather emphasize the environmental limits of each

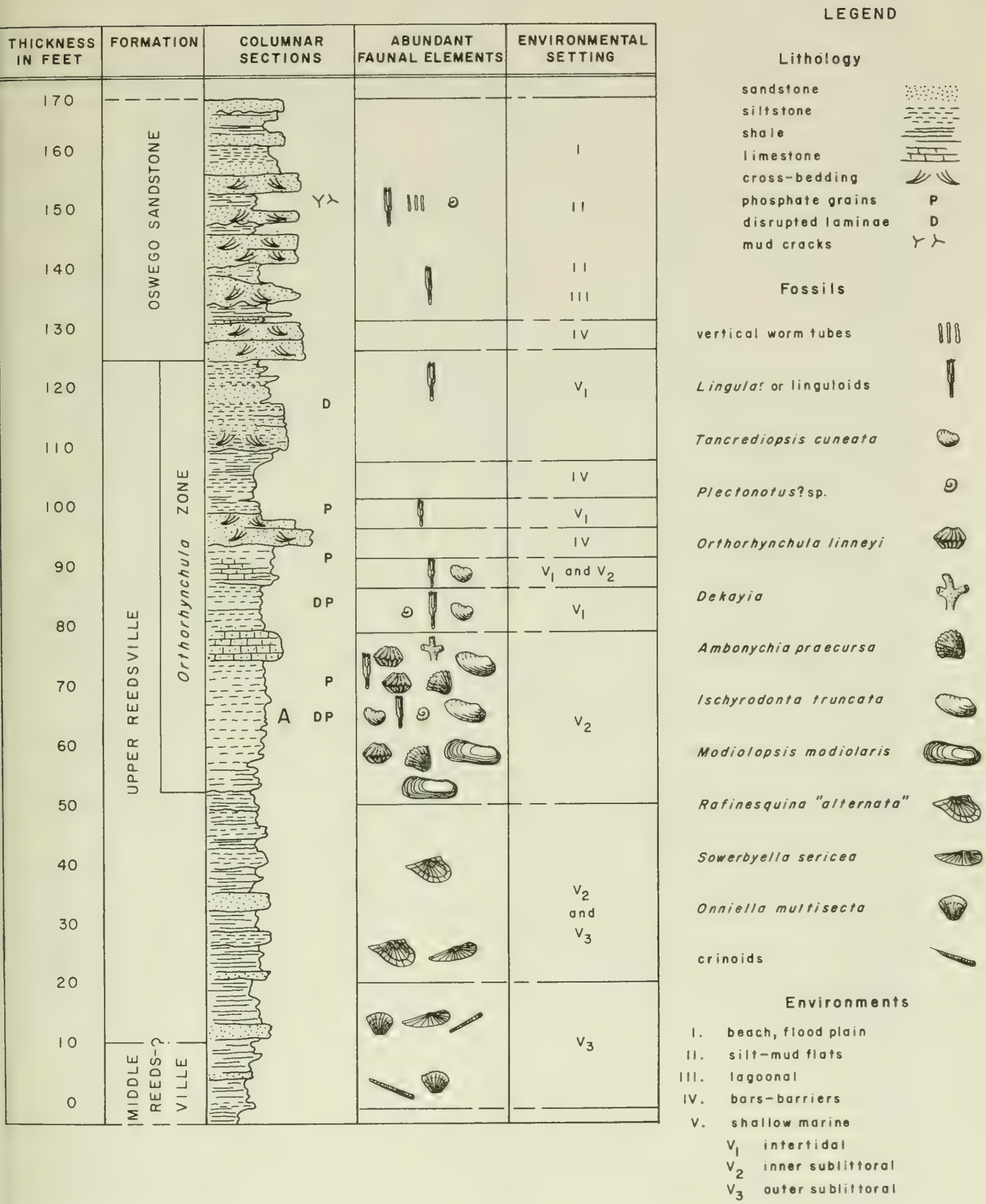

THICKNESS IN FEET
FORMATION
COLUMNAR SECTIONS
ABUNDANT FAUNAL ELEMENTS
ENVIRONMENTAL SETTING
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
OSWEGO SANDSTONE
UPPER REEDSVILLE
Orthorhynchula ZONE
MIDDLE REEDS-? VILLE
D
P
P
DP
P
A
DP
I
II
II
III
IV
V1
IV
V1
IV
V1 and V2
V1
V2
V2 and V3
V3
LEGEND
Lithology
sandstone
siltstone
shale
limestone
cross-bedding
phosphate grains P
disrupted laminae D
mud cracks
Fossils
vertical worm tubes
Lingula? or linguloids
Tancrediopsis cuneata
Plectonotus? sp.
Orthorhynchula linneyi
Dekayia
Ambonychia praecursa
Ischyrodonta truncata
Modiolopsis modiolaris
Rafinesquina "alternata"
Sowerbyella sericea
Onniella multisecta
crinoids
Environments
I. beach, flood plain
II. silt-mud flats
III. lagoonal
IV. bars-barriers
V. shallow marine
V1 intertidal
V2 inner sublittoral
V3 outer sublittoral

FIG. 7. Composite upper Reedsville—Oswego columnar section from eastern West Virginia and south-central Pennsylvania emphasizing a detailed lithologic and faunal correlation. Only abundant faunas are noted and the interpretation of environmental settings are outlined in text. Top of the *Orthorhynchula* Zone placed at last occurrence of *Lingula*? and bottom of zone where abundant *Modiolopsis modiolaris* disappear. The letter "A" marks a bed in that portion of the section at locality 203 in West Virginia that was sectioned and photographed (see Pl. 1).

fossil community and place it in environmental perspective, both temporally and geographically.

It is generally held that the orthid, strophomenid and spiriferid brachiopods and the modiolopsid bivalves in the upper Reedsville strata in southern Pennsylvania and eastern West Virginia indicate that these strata are time-correlative with those of the Pulaski Sandstone of western New York. (See Woodward, 1951, p. 371–376; Willard, 1943, p. 1103–1106; Butts, 1940, p. 218). The orthid and atrypid brachiopods in these fossiliferous units in southwestern Virginia and northern Tennessee (Butts, 1940, p. 218), as well as the Pulaski brachiopod and bivalve mollusc fauna (Foerste, 1924; Ruedemann, 1925a), have been correlated with those in the Fairview Formation in the Cincinnatian type area; this correlation implies a lower Maysvillian age for the fossiliferous strata at the top of the Reedsville. Peck (1966) and Ford (1965, 1967), in their revision of the Upper Ordovician formations in the Maysville and Cincinnati regions, have retained the term Fairview Formation and have redefined it as a rock-stratigraphic unit, but it is essentially the same unit as the earlier faunally defined "Fairview Formation" because the faunal breaks occur where major lithologic changes take place; therefore, the correlation originally made will remain about the same (John Pojeta, pers. comm.).

The stratigraphic interval represented by the *Orthorhynchula* Zone and other stratigraphically equivalent fossiliferous units at the top of the Reedsville and Martinsburg Formations varies between 50 and 200 feet, reaching a maximum thickness in central and eastern Pennsylvania and south-central Virginia, and thinning to less than 100 feet in eastern Western Virginia and north-central Virginia (Fig. 5). Thickness measurements in southwestern Virginia and northern Tennessee vary between 50 and 150 feet. Specifically, the *Orthorhynchula* Zone constitutes about the upper 20 to 60 feet of the upper Reedsville in south-central Pennsylvania. The zone thickens to about 100 feet in eastern West Virginia, and thicknesses of 50 to 125 feet are common in west-central and south-central Virginia, where the total thickness of the fossiliferous rocks of the upper Reedsville may range from 100 to 200 feet.

Figure 8 outlines the general geographic limits of the fossiliferous upper Reedsville and Martinsburg rocks, which extend from the western edge of the Appalachian Valley and Ridge Province into the Great Valley to the east. The maximum width of the belt occasionally approaches 100 miles, but it is usually less than 50 miles wide. (Note that Fig. 8 has a palinspastic base.) The length of the outcrop belt is over 600 miles.

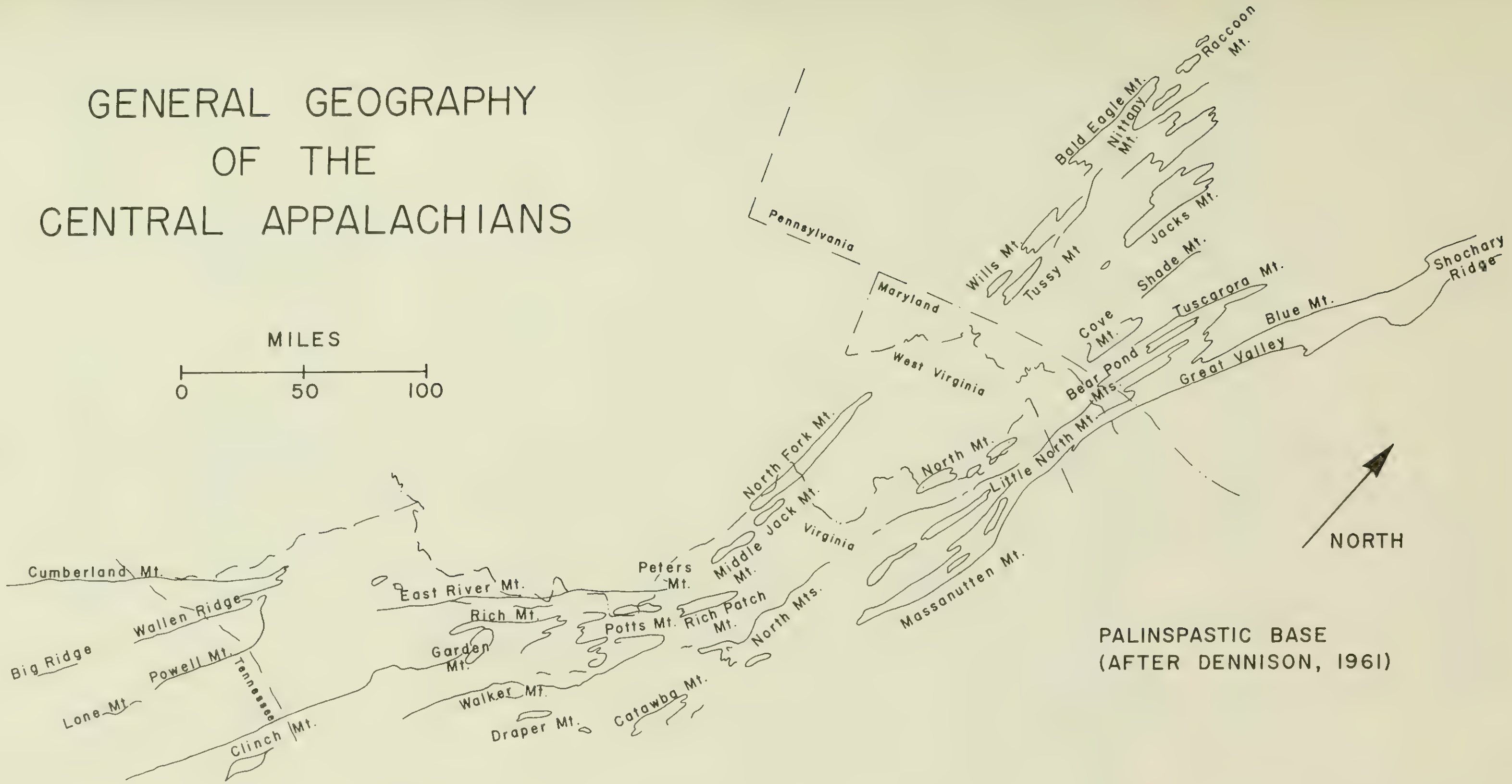

GENERAL GEOGRAPHY
OF THE
CENTRAL APPALACHIANS
MILES
0
50
100
PALINSPASTIC BASE
(AFTER DENNISON, 1961)
NORTH
Pennsylvania
Maryland
West Virginia
Virginia
Tennessee
Raccoon Mt.
Bald Eagle Mt.
Nittany Mt.
Jacks Mt.
Wills Mt
Tussy Mt
Shade Mt.
Tuscarora Mt.
Cove Mt.
Bear Pond Mts.
Blue Mt.
Great Valley
Shochary Ridge
North Fork Mt.
North Mt.
Little North Mt.
Jack Mt.
Middle Mt.
Massanutten Mt.
Peters Mt.
Rich Patch Mt.
North Mts.
Potts Mt.
Cumberland Mt.
East River Mt.
Rich Mt.
Garden Mt.
Wallen Ridge
Big Ridge
Powell Mt.
Lone Mt.
Clinch Mt.
Walker Mt.
Draper Mt.
Catawba Mt.

FIG. 8. Outline of geographic limits of the fossiliferous upper Reedsville and Martinsburg rocks, which extend from the western edge of the Appalachian Valley and Ridge Province into the Great Valley to the east. The lines on the map are the Reedsville-Martinsburg outcrop pattern and hence outline the Appalachian ridges where the rocks are exposed.

ENVIRONMENTAL INTERPRETATIONS FROM STRATIGRAPHIC AND SEDIMENTOLOGICAL EVIDENCE

Earlier sedimentological and stratigraphic studies in the north-central Appalachian Upper Ordovician have provided a broad outline of the probable environments of deposition of these predominantly clastic sediments. Most investigators working in the Oswego (= Bald Eagle) and Juniata Formations that overlie the fossiliferous units at the top of the Reedsville and Martinsburg(?) Formations agree that the source of the sediment was to the east; these workers have also provided evidence of a progressive uplift of the source area, resulting in a westward progradation of the depositional environments throughout Late Ordovician time. Evidence of this regression comes from numerous previously measured sections that show a gradual increase in grain size from the shales of the lower part of the Reedsville upward through the sandstones and conglomerates of the Oswego and Juniata. The geometric shape and primary sedimentary structures of the upper parts of the Oswego and the entire Juniata support the hypothesis of an eastern source area and westward progradation, as both exhibit predominantly west-dipping cross beds that outline a broad, fan-shaped regional current pattern. Figure 9 is a reconstruction of the east to west progradation of the Upper Ordovician formations based on the stratigraphic-sedimentological evidence. The "time lines" are diagrammatic, not based on specific faunal evidence, but again reflect the overall stratigraphic pattern. The apron-like thinning of the Oswego and the associated decrease in the overall grain size from east to west imply a source area extending from eastern Pennsylvania to northern Virginia, and a westward transport of detritus (Yeakel, 1962, p. 1533). Measurements of cross-bedding in the Juniata sandstones reveal a dispersal pattern similar to that of the Oswego. Therefore all available evidence points to a general north-south strike and westward primary dip of the Late Ordovician sea floor.

Previous investigators working in the north-central Appalachians have interpreted the siltstones and shales of the lower and middle parts of the Reedsville Formation as marine and the sandstones of the upper parts of the Oswego and the Juniata Formations as alluvial or flood plain deposits. There is much less agreement as to the depositional environments of the sandstones and siltstones of the upper Reedsville and of the sandstone of the lower Oswego in southern Pennsylvania, eastern West Virginia and west-central Virginia. A Late Ordovician littoral environment exists in these rocks between the obviously marine and obviously terrestrial beds.

Grabau (1913, p. 440–441) proposed that the Oswego sandstones in Pennsylvania represented the terrestrial part of a prograding delta and that the Reedsville formed its marine equivalent. Yeakel (1962, p. 1534) generally agreed with Grabau and at-

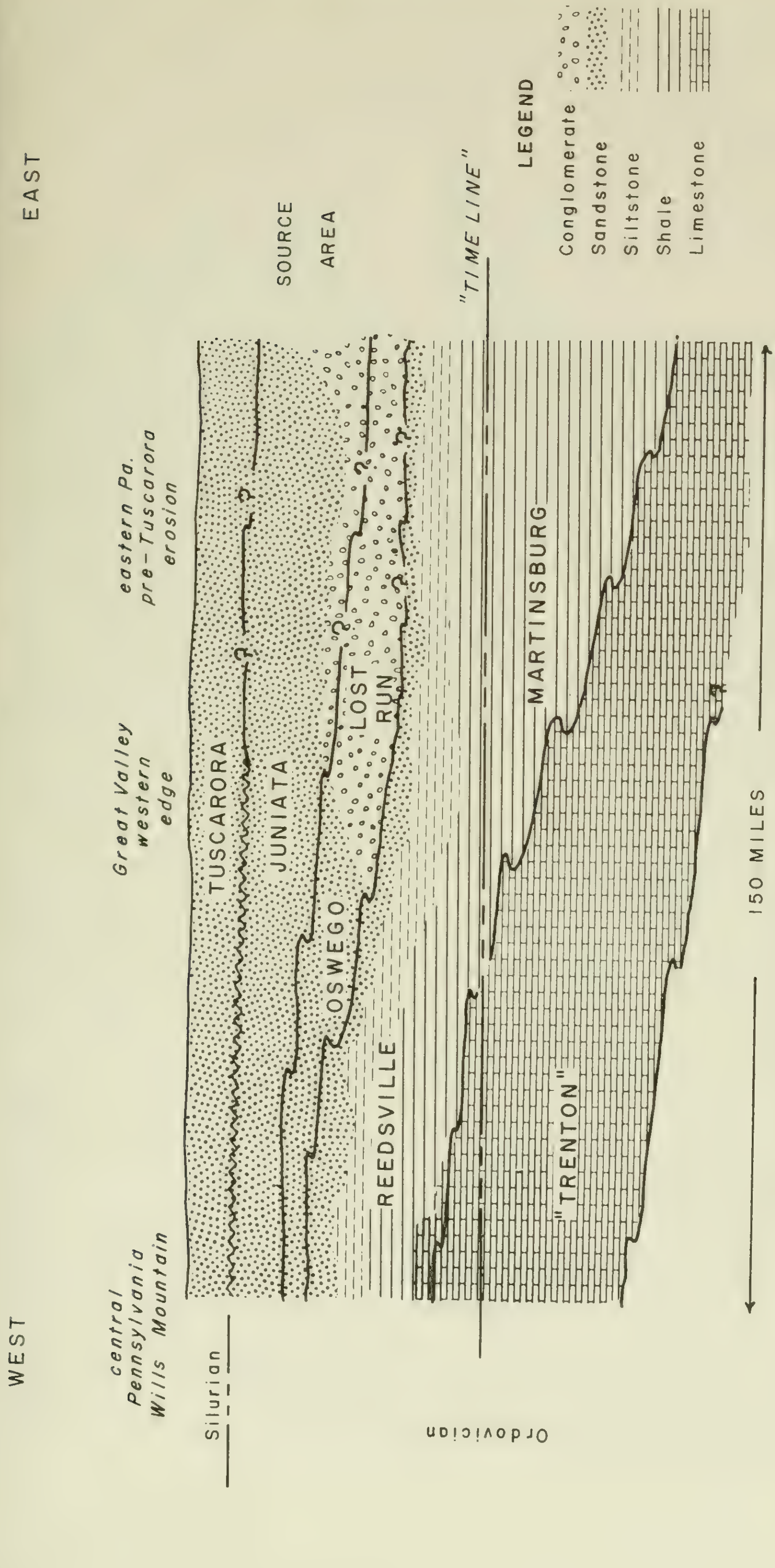

WEST
EAST
central Pennsylvania Wills Mountain
Great Valley western edge
eastern Pa. pre-Tuscarora erosion
SOURCE AREA
Silurian
Ordovician
TUSCARORA
JUNIATA
OSWEGO
LOST RUN
REEDSVILLE
MARTINSBURG
"TRENTON"
"TIME LINE"
150 MILES
LEGEND
Conglomerate
Sandstone
Siltstone
Shale
Limestone

FIG. 9. Reconstruction of a probable east to west migration of the Upper Ordovician formations in Pennsylvania and northern Virginia. Interpretations are made from previous stratigraphic and sedimentological studies (McBride, 1960; Yeakel, 1962; Horowitz, 1965). The source of terrigenous clastics was to the east and uplift appears to have occurred throughout the Late Ordovician. This figure is diagrammatic and there is no inference as to rates of progradation. The interval represented by the *Orthorhynchula* Zone would lie at the top of the Reedsville Formation in central Pennsylvania.

tempted to demonstrate that the Bald Eagle (= Oswego) was largely an alluvial deposit. Pierce (1966, p. 29), however, working in the same area, interpreted the Oswego as a shallow marine deposit. Krynine (1960) considered the transitional Oswego-Reedsville complex in south-central Pennsylvania as a beach, lagoonal and open-sea system. Woodward (1951, p. 381), in his review of the Ordovician stratigraphy of eastern West Virginia, interpreted the lower part of the Oswego as a shallow marine deposit and the upper part as a subaerial delta.

Two recent studies compared the Late Ordovician environments with more precisely defined modern depositional regimes. Horowitz (1965, 1966), working in south-central Pennsylvania and eastern West Virginia, revised Grabau's (1913) concept, and pictured a broad, nearshore marine, deltaic environment; Horowitz found analogues in the uppermost Reedsville and lower Oswego for Recent topset, foreset and bottomset beds. Thompson (1967), also working in south-central Pennsylvania, followed Krynine (1960) in proposing a beach, lagoonal and barrier-bar model for the same sequence of upper Reedsville and lower Oswego sediments. Horowitz (1965, 1966) considered the fossiliferous shales, shaly siltstones and sandstones at the top of the Reedsville to be the foresets of a Late Ordovician delta or coalescing smaller deltas, whereas Thompson (1967) believed them to represent a very shallow marine, almost intertidal environment situated immediately seaward of a barrier-lagoonal complex.

Irrespective of the details of the Late Ordovician depositional environment, the sediments of the upper Reedsville Formation formed nearshore marine deposits, possibly intertidal in part, but certainly inner sublittoral. In Pennsylvania and West Virginia these sandstones and siltstones are moderately sorted, perhaps suggesting deposition in areas which were occasionally washed by waves and currents. Cross-laminae are evident and presumably were produced by gentle current reworking, but more often in the upper parts of the fossiliferous horizon (especially in Pennsylvania and West Virginia) the effect of washing appears to have been destroyed by the activity of burrowing organisms or soft-sediment deformation. Plate 1 is a section cut from the *Orthorhynchula* Zone in eastern West Virginia (locality 203, A-6304, about 70 feet below the Oswego-Reedsville contact, see Fig. 8). Donald Rhoads (pers. comm.) has pointed out similar disrupted sedimentary structures in a core taken from a Recent muddy silt environment in Buzzards Bay, Massachusetts, in about 20 meters of water (Station R of Sanders, 1958, p. 246, fig. 1). The mixing of the Recent sediment is attributed to reworking by organisms.

One other indication of the possible shallow water origin for the upper Reedsville sediments is found in the occurrence of fine to medium sand size phosphate grains that often occur in the massive, biogenically reworked layers (see Pl. 1). Unfortunately the origin of shallow water phosphate is not well known. Bushinski (1964) and d'Angeljan-Chatillon (1965, 1967) have surveyed the subject, contrasting the scanty Recent observations with better documented geologic examples, most of which seem in some need of reinterpretation. D'Angeljan-Chatillon (1965), studying the marine platform off the west coast of Baja California, has found that the highest concentration of phosphate grains occurs in a sandy shelf sediment from the coastal lagoons to 100 meters water depth. The grains are well sorted, possibly because of their mode of formation as internal molds of Foraminifera, and encrust detrital materials. The replacement of internal molds and fecal pellets by phosphate appears to require the following conditions: 1) slightly positive Eh; 2) shallow depth; 3) high organic productivity (upwelling waters from deep ocean basins rich in P_2O_5 will encourage high secondary productivity in shallow water, see Fig. 11); and 4) low rate of sedimentation (concentrations found only in condensed deposit).

Bushinski (1964) hypothesized from the data of Bruevitch and Saitzeva (1958), working in the Bering Sea, that muddy silts situated in hollows between shoals are especially rich in dissolved phosphate. The incipient grains would form in the oxygen-poor hollows (Youssef, 1965), and intermittent periods of turbulence reaching into this stagnant regime would rework and redistribute the partially consolidated grains on the shallow marine shelf. The biochemical and bacterial processes of phosphate concentration in shallow water areas are, however, virtually unknown.

The phosphate in the central Appalachian Upper Ordovician deposits appears to encrust finer detrital quartz sands and silts, in addition to being complete or partial internal molds of small bellerophontid gastropods (*Plectonotus*? sp.); associated with these grains are phosphatic shell debris (usually linguloid brachiopod fragments), phosphate cement and small apatite crystals. The original calcareous shell material is usually dissolved or worn away, but occasionally the walls of trepostomatous bryozoans (*Dekayia*) show complete replacement of the calcite by phosphate. The grains usually constitute less than 5 per cent of the sediment, are usually smooth and appear to have undergone some agitation, but seem to have formed in areas generally protected from strong wave and tidal current activity. The currents were strong enough to wash out much of the clay-sized fraction and alter the shape of most of the grains (e.g. irregularly shaped internal molds of *Plectonotus*? sp. seem to have resulted from reworking). Phosphate-encrusted sand grains are usually well sorted, but the phosphate grains are rare where there is a high percentage of sands and normally are found within the highly reworked beds interbedded with the cross-bedded bar and barrier sands. This association probably indicates a shallowing trend accompanied by a decrease in oceanic circulation. The occasional phosphate pseudomorphs of calcareous shell material (e.g., *Dekayia*) and the complete biogenic reworking of the muddy silts presumably indicate a slow accumulation of sediments. The P_2O_5 is probably taken out of the nearshore waters by abundant planktonic organisms that upon death sink to the shallow bottom; in order for the phosphate to remain, there must be little circulation on the way down and no resuspension of the bottom mud until the grains have had a chance to harden and to replace shell material.

In a summation of the previous sedimentological-stratigraphic interpretations of the central Appalachian Upper Ordovician strata, it is apparent that the transitional nearshore marine environments in the upper Reedsville and lower Oswego Formations appear to have covered an area from south-central Pennsylvania into eastern Virginia and adjoining parts of west-central Virginia. The Oswego Sandstone in north-central Pennsylvania is, however, alluvial or flood plain in origin (Yeakel, 1962), with occasional large-scale festoon cross beds. The Oswego-Reedsville contact in this area of the central Appalachians is probably erosional. Here a major deltaic complex may have developed, accompanied by high rates of sedimentation and vigorous erosion as the complex prograded westward. The erosional unconformity becomes more evident to the east with an associated development of a thick conglomeratic facies. It seems reasonable that near this major terrigenous source area a high sediment influx prevented either the formation or the preservation of many of the

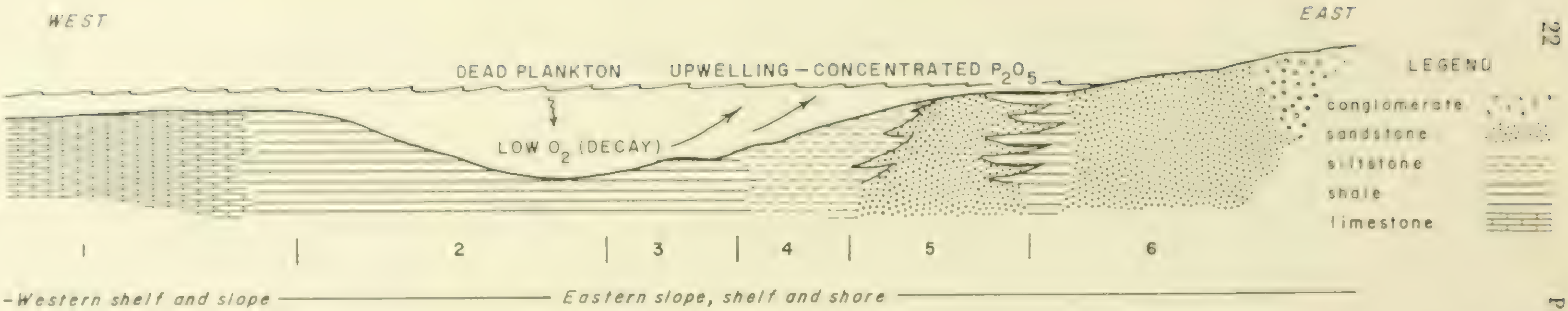

WEST
EAST
DEAD PLANKTON
UPWELLING – CONCENTRATED P_2O_5
LOW O_2 (DECAY)
LEGEND
conglomerate
sandstone
siltstone
shale
limestone
1
2
3
4
5
6
Western shelf and slope
Eastern slope, shelf and shore

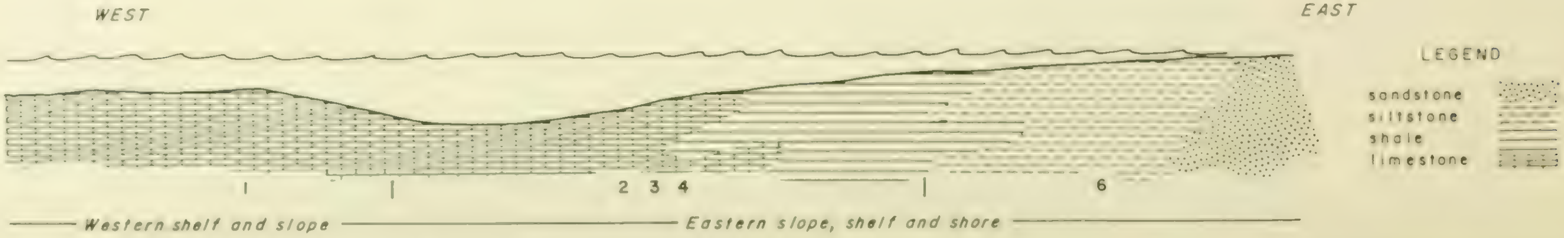
FIG. 10. Reconstruction of the onshore to offshore profile (east-west) during the Late Ordovician in the north-central Appalachians. Numerals refer to bathymetric environments and are also used in Figures 11 and 12.

Western Shelf and Slope(?)

1. Cincinnatian limestones and shales—shallow sublittoral, continental seas.
2. Lower Reedsville mud—bathyl(?) and outer sublittoral area of low O_2 concentration, stagnant basin environment; therefore, decay and upwelling of P_2O_5 eastward toward shallow shelf providing for high primary productivity.

Eastern Slope(?), Shelf and Shore

3. Middle Reedsville mud, silt and limestone coquinas—outer sublittoral and bathyl(?), turbidites of eastern origin common.
4. Upper Reedsville muddy silts and sands—inner sublittoral and possibly intertidal, prolific bottom fauna, *Orthorhynchula* Zone, results from upwelling from depths thus allowing high primary productivity.
5. Lower part of Oswego Sandstone, coarse cross-bedded sands and interbedded muds—beach, bar and lagoonal environments.
6. Upper part of Oswego Sandstone, Lost Run Conglomerate and Juniata Sandstone—deltaic, flood plain and alluvial environments.


WEST
EAST
LEGEND
sandstone
siltstone
shale
limestone
1
2 3 4
6
Western shelf and slope
Eastern slope, shelf and shore

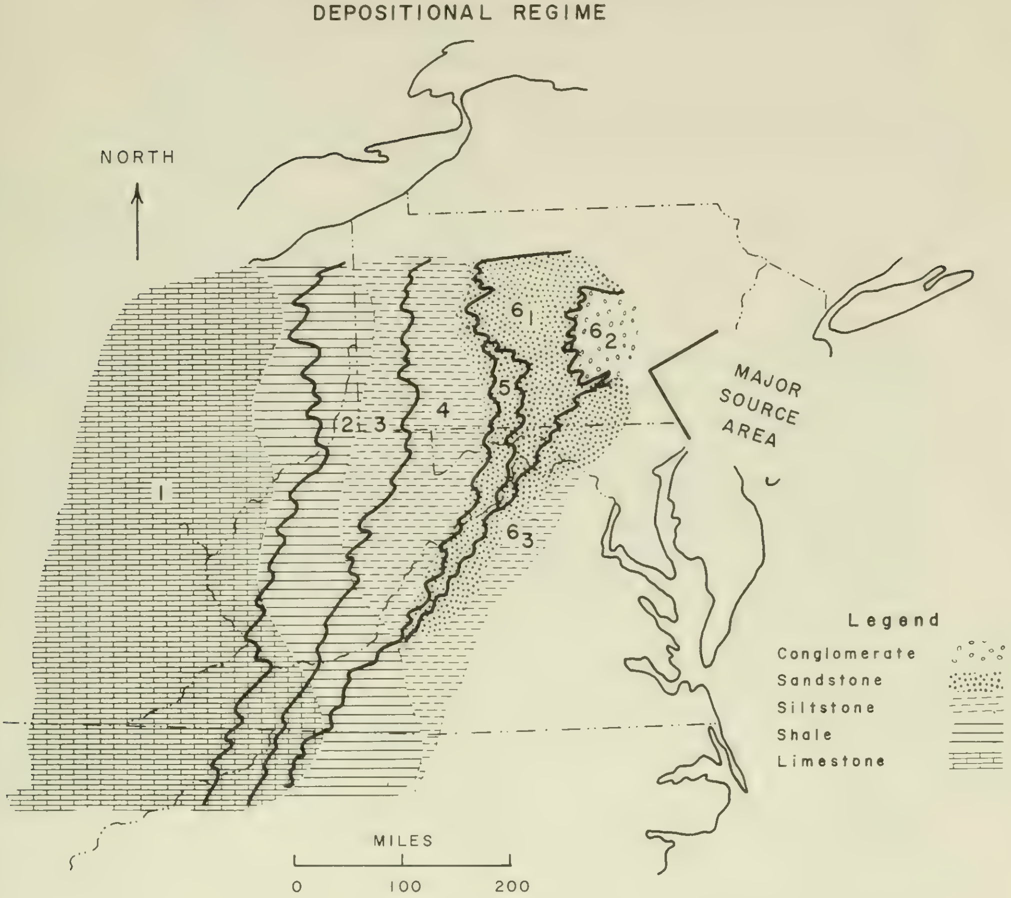

DEPOSITIONAL REGIME
NORTH
1
2
3
4
5
6₁
6₂
6₃
MAJOR SOURCE AREA
Legend
Conglomerate
Sandstone
Siltstone
Shale
Limestone
MILES
0
100
200

FIG. 12. Reconstruction of the depositional environments during the Late Ordovician in the central Appalachians (see Figs. 10 and 11 for a more complete description of the environments).

1. Western shelf carbonates—Cincinnatian limestones.
2. and 3. Western slope (?) and eastern slope (?), outer shelf muds and silts—lower part of Reedsville.
4. Eastern inner shelf silts and sands—upper part of Reedsville.
5. Barrier and beach coarse sands, lagoonal muds—lower part of Oswego Sandstone.
6. Flood plain silts and sands, alluvial sands and conglomerates.
   6_1—Oswego 6_2—Lost Run 6_3—Juniata

FIG. 11. Reconstruction of the onshore to offshore profile (east-west) during the Late Ordovician in southwestern Virginia and northern Tennessee. Numerals refer to bathymetric environments and are also used in Figures 10 and 12. Note that there are no lower Oswego beach, bar and lagoonal environments (5. in Fig. 10) in the south.

Western Shelf: 1. Cincinnatian limestones—shallow sublittoral, continental seas.

Eastern Shelf and Shore: 2. 3. and 4. Reedsville silty muds, muds and lime muds—sublittoral and possibly intertidal environments. 6. Juniata muds, silts and sands—flood plain and alluvial environments.

ephemeral shoreline features — barrier, bar and lagoonal deposits — that are seen farther to the south in south-central Pennsylvania, eastern West Virginia and north-central Virginia. It does seem possible, however, that some of the considerable quantities of the lower Oswego barrier-bar-forming sands may have initially been deposited in central Pennsylvania and then redeposited by longshore currents to the south.

The Oswego (= Bald Eagle) is not present south of west-central Virginia and I believe that near Middle Mountain, Virginia (Fig. 1, loc. 194) the few tens of feet of Oswego Sandstone represent the termination of the north-to-south longshore deposits. The reddish Juniata sandstones are more poorly sorted in the south-central Appalachians and contain a notably higher percentage of shale beds. The entire depositional regime in southwestern Virginia and northern Tennessee appears to represent a low-energy environment, probably a broad fluctuating subaqueous and subaerial flood plain, receiving much less terrigenous clastic material than the more northern areas.

Figures 10 to 12 combine these concepts into cross-sections together with a map of the Upper Ordovician sedimentological environments as they probably appeared on the Late Ordovician shelf in the central Appalachians. This reconstruction will provide the framework on which the zoogeographic distributions of the Late Ordovician faunal communities will be charted.

FAUNAS

INTRODUCTION

Numerically dominant taxonomic groups throughout the central Appalachian Upper Ordovician fauna are the bryozoans, the brachiopods, the gastropods and the bivalves. Trilobites and crinoids are abundant but only in the north-central Appalachians and presumably are restricted ecologically. The fossils are distributed throughout the upper Reedsville and equivalent Martinsburg strata; they are uncommon in the lower parts of the Oswego in the north-central Appalachians and in the lower parts of the Juniata and Sequachie in the south. The fossils, concentrated in layers and lenses, are usually preserved as composite, internal or external molds. The valves of bivalves and brachiopods are frequently disarticulated but show little evidence of surface wear or breakage. Obvious pelomorphic distortion of the fossil material has resulted from compaction on the bedding plane and from subsequent tectonic events in the folded and faulted Valley and Ridge Province. Calcareous shell material is never present in the gastropods, is scarce and completely recrystallized in a few bivalves, and has been preserved only in the brachiopods and bryozoans.

Table 1 is a list of the genera and/or species which are discussed in the chapter on systematic paleontology. About 5,100 specimens were collected from 164 localities

TABLE 1. Genera and/or species reviewed in the chapter on systematic paleontology.

BRYOZOA
- *Monticulipora*
- *Dekayia*
- *Batostomella*
- *Amplexopora*
- *Hallopora*

BRACHIOPODA
- *Lingula*?
- *Hebertella sinuata*
- *Onniella multisecta*
- *Sowerbyella* (*Sowerbyella*) *sericea*
- *Rafinesquina* "*alternata*"
- *Orthorhynchula linneyi*
- *Zygospira modesta*
- *Zygospira recurvirostra*

GASTROPODA
- *Plectonotus*? sp.
- *Bucania* sp.
- *Loxoplocus* (*Lophospira*) *abbreviata*
- *L.* (*L.*) *perangulata*
- *L.* (*L.*) *ventricosta*
- *Ruedemannia*? *lirata*
- *Sinuopea*?
- *Murchisonia*?

BIVALVIA
- *Tancrediopsis cuneata*
- *Ctenodonta*? *pulchella*
- *Praenucula levata*
- *Ambonychia radiata*
- *A. praecursa*
- *A. cultrata*
- ?*A. byrnesi*
- *Pterinea* (*Caritodens*) *demissa*
- *Modiolopsis modiolaris*
- *Ischyrodonta*? *trunçata*
- *Lyrodesma poststriatum*

throughout the central Appalachians. There are about 35 abundant species in the rocks of the central Appalachian Upper Ordovician; some less numerous species are not described but occasionally are referred to in various systematic discussion. No attempt has been made to compile a complete list of central Appalachian Upper Ordovician species; the reader is referred to Butts (1941) and Woodward (1951) for such lists.

No specific sampling techiniques for determination of species density had been designed prior to the start of the project; initial field examinations of a few well-known exposures emphasized the difficulties of utilizing a standardized sampling technique (e. g. counts of specimens per unit area of rock) because of the wide variation in area of exposed rock from locality to locality. Several random grid and line methods were attempted at a few exposures and at various stratigraphic intervals in order to determine the absolute abundance or density of particular species (see Ager, 1963, p. 220–230), but it was decided that in this introductory study reasonably accurate estimates of species density could be obtained if a relative scale of taxonomic density was constructed and applied at each locality. Table 2 shows this relative scale and the equivalent absolute scale. Species ranking at 3 or greater on the relative scale (i.e., specimens numbering 25 or more per 100 square feet) are considered to be abundant. Table 3 (in pocket) is a compilation of the relative species abundances at each locality sampled in the central Appalachians and forms the basis for the synthesis of species into multi-species populations and communities.

TABLE 2. Taxonomic density scale.

Relative abundance notation	Absolute number of specimens per 100 square feet
1	1–9
2	10–24
3	25–99
4	100–250
5	250

Taxa were identified in the field and relative abundance recorded at each locality, along with the stratigraphic relationships and associated lithology. At only 37 of the 164 localities were the actual absolute counts of species density recorded. These preliminary results were refined in the laboratory after the taxa had been re-examined. I found that the density of the most abundant species often varied from 3 to 5 on the relative abundance scale only a few tens of miles apart. This variation may reflect actual differences in density, but in some cases may be an artifact of the areal extent and degree of weathering of the exposure. What is important, however, is the consistent stratigraphic and zoogeographic re-occurrence of these same species, which permits the outlining of Ordovician faunal populations and communities.

ZOOGEOGRAPHY

The distributional patterns of the central Appalachian Upper Ordovician bryozoans, brachiopods, gastropods and bivalves are shown in Figures 13, 14, 16 and 17. By systematically segregating each of these major faunas it was hoped that the distributional patterns, both geographically and stratigraphically within the upper Reedsville, would be distinctive enough to aid in more detailed interpretations of the Late Ordovician marine environments. All inferences and interpretations from this zoogeographic data have been incorporated into the following chapters on paleoautecology and community structure.

Recognition of a systematically consistent portion of a major taxonomic group occupying and dominating a particular geographic region has led to the use of the term "faunal province". Any abrupt change in the faunal composition of the upper Reedsville strata will define a provincial boundary. Provincial overlap takes place and may be accompanied by an intermingling of species or a distinct stratigraphic separation of the faunas, still within the upper Reedsville strata.

Bryozoa

The distribution of the bryozoans of the central Appalachian Upper Ordovician is shown in Figure 13. The bryozoan fauna can be divided into three smaller faunal provinces designated I, II and III. These faunal provinces are strictly defined by the existing geographic limits of the bryozoan faunas and incorporate no interpretations of probable Ordovician distributional patterns which are reserved for the following two chapters. Two of the provinces show domination by a single genus (Table 4). Generally the provinces are distinct geographically, although there is some faunal overlap between bryozoan provinces II and III in south-central Virginia (Fig. 13). This overlap between II and III shows no stratigraphic separation but rather a mingling of the faunas. Bryozoan province I, although exhibiting considerable geographic separation from province II, is believed to occur considerably lower in the upper Reedsville stratigraphic section than do those faunas of province II. All of the abundant bryozoan genera composing these three faunal provinces are trepostomes.

TABLE 4. Bryozoan faunal provinces. See also Fig. 13.

	Location	Abundant Fauna
I	North-central Pennsylvania	*Hallopora*
II	Eastern West Virginia and west-central Virginia	*Dekayia*
III	Southwestern Virginia and northern Tennessee	*Monticulipora* *Dekayia* *Batostomella* *Amplexopora* *Hallopora* *Heterotrypa* Peronoporid

Brachiopoda

The zoogeographic pattern of the brachiopods also outlines three main faunal provinces, designated I, II and III (Fig. 14). There is a more pronounced geographic overlap of the brachiopod faunas at the boundaries of the provinces, in contrast to the almost complete separation of the bryozoan faunal provinces. Table 5 presents the abundant faunal elements in each brachiopod province.

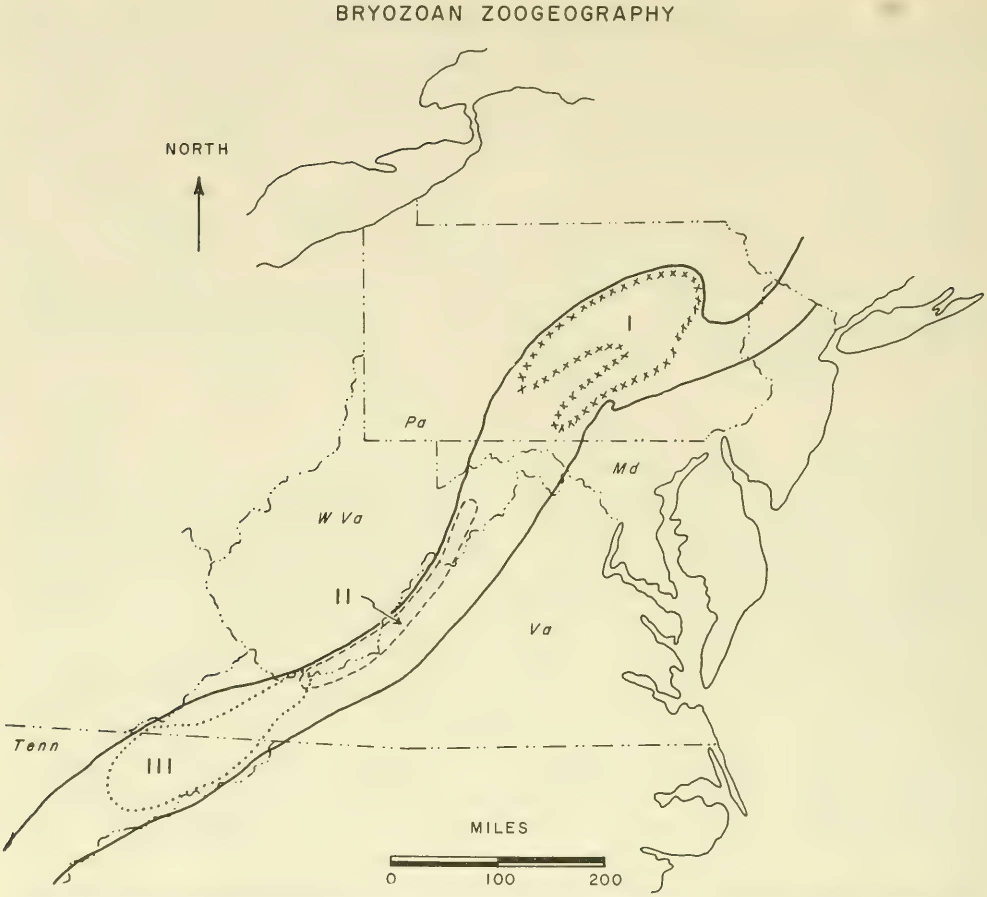


FIG. 13. A generalized outline of the most abundant trepostomatous bryozoan genera in the central Appalachian Upper Ordovician. Three main bryozoan faunal provinces:

I. *Hallopora*
II. *Dekayia*
III. *Monticulipora*
Dekayia
Hallopora
Batostomella
Amplexopora

TABLE 5. Brachiopod faunal provinces. See also Fig. 14.

	Location	Abundant Fauna
I	Eastern Pennsylvania, central Pennsylvania and northern Virginia	*Rafinesquina "alternata"* *Sowerbyella (Sowerbyella) sericea* *Onniella multisecta* *Zygospira modesta*
II	South-central Pennsylvania to south-central Virginia	*Lingula?* *Orthorhynchula linneyi*
III	Southwestern Virginia and northern Tennessee	*Hebertella sinuata* *Zygospira recurvirostra*

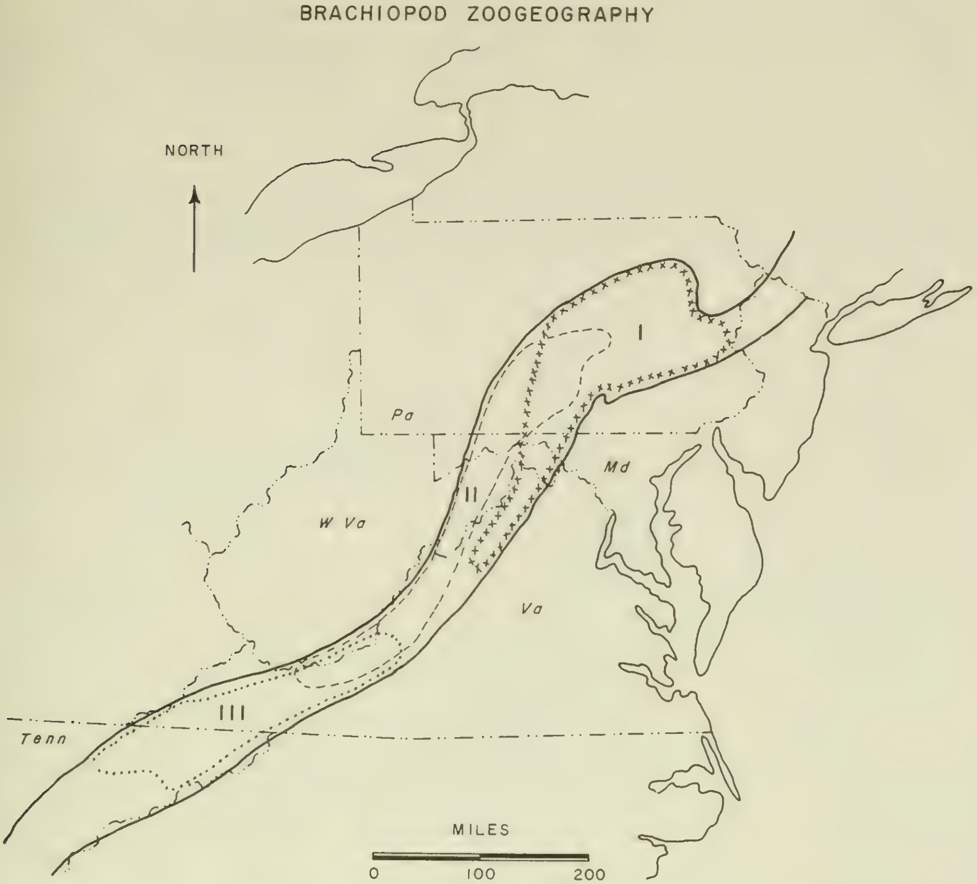


FIG. 14. A generalized outline of the distribution of the most abundant brachiopod species in the central Appalachian Upper Ordovician. The three major brachiopod faunal provinces are:

I. *Sowerbyella (Sowerbyella) sericea*
Rafinesquina "alternata"
Onniella multisecta
II. *Lingula?*
Orthorhynchula linneyi
III. *Hebertella sinuata*
Zygospira recurvirostra

Note that overlap of the brachiopod provinces may not result in actual mixing of two faunas since the faunas are separated stratigraphically (see Fig. 15).

Brachiopod province I, predominantly composed of orthids and strophomenids, overlaps brachiopod province II. There is, however, only a very limited mixing of the associated abundant species, because province I is stratigraphically lower than province II (Fig. 15). The fauna of brachiopod provinces I and II exhibit a fairly regular succession of species; in province I strophomenids far outnumber the stratigraphically lower orthids and spiriferids (Fig. 15). Province II, an assemblage of rhynchonellid and linguloid brachiopods, occupies the mid-portion of the central Appalachians and is usually confined to the westernmost upper Reedsville exposures. In province II the

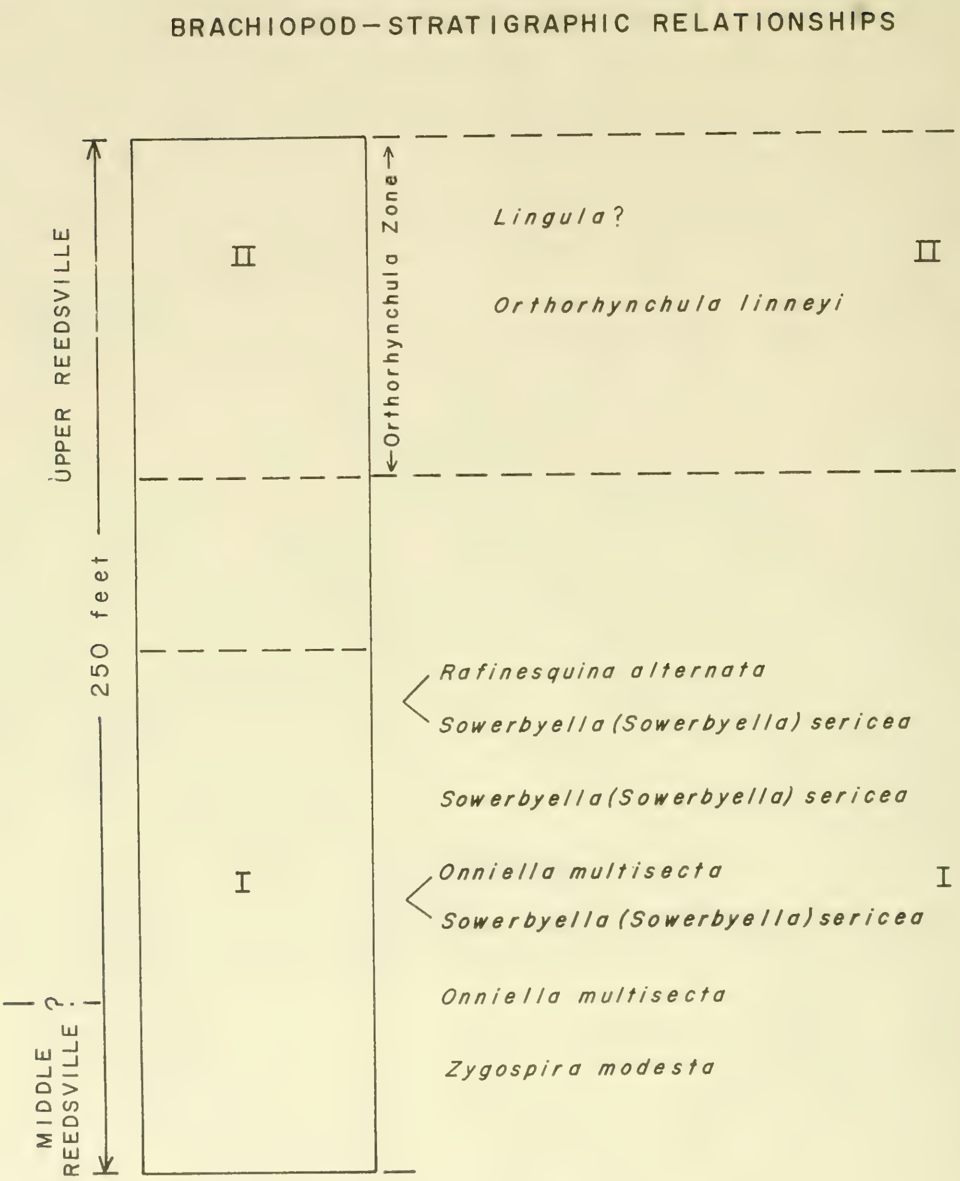

BRACHIOPOD–STRATIGRAPHIC RELATIONSHIPS
UPPER REEDSVILLE
250 feet
MIDDLE REEDSVILLE ?
II
I
←Orthorhynchula Zone→
Lingula?
Orthorhynchula linneyi
II
Rafinesquina alternata
Sowerbyella (Sowerbyella) sericea
Sowerbyella (Sowerbyella) sericea
Onniella multisecta
Sowerbyella (Sowerbyella) sericea
Onniella multisecta
Zygospira modesta
I

FIG. 15. A composite columnar section from the upper and middle(?) Reedsville in south-central Pennsylvania showing the stratigraphic-faunal separation of brachiopod provinces I and II. See Figure 14 for geographic extent of this overlap.

stratigraphic succession of the faunas follows a pattern whereby the linguloids overlie the rhynchonellids (Fig. 15). Brachiopod province III, dominated by orthids and spiriferids, broadly overlaps province II in southwestern Virginia, but there is no marked stratigraphic separation of the faunas. In the southern part of the mixed zone the linguloids of province II disappear suddenly, but *Orthorhynchula linneyi* is gradually outnumbered by *Hebertella sinuata.* The two dominant species of brachiopod province III, *Hebertella sinuata* and *Zygospira recurvirostra*, only occasionally occur together; they do not occur in any characteristic stratigraphic order as did the species in brachiopod provinces I and II.

Gastropoda

The distributional pattern of the gastropods is presented in Figure 16. Each of the three gastropod faunal provinces is dominated by species of only one superfamily

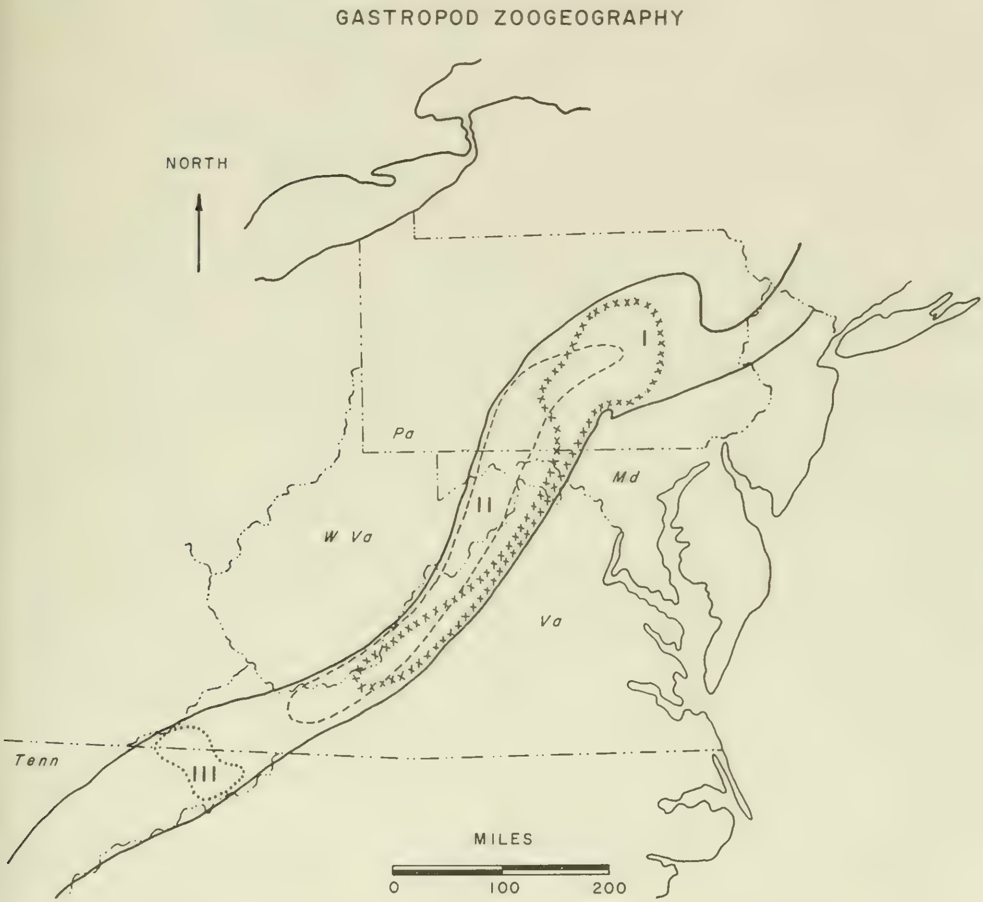


FIG. 16. A generalized outline of the distribution of the most common gastropod species in the central Appalachian Upper Ordovician. The three major gastropod faunal provinces are:

I. Pleurotomariid
  Loxoplocus (*Lophospira*) spp.
  Ruedemannia? *lirata*
  Sinuopea?
II. Bellerophontid
  Plectonotus? sp.
  Bucania sp.
III. Murchisoniid
  Murchisonia?

Note that in this instance mixing of the faunas in gastropod provinces I and II occurs where overlap takes place.

(Table 6). Gastropod zoogeography shows strikingly consistent pattern in the central Appalachians throughout the Late Ordovician. Three gastropod provinces have been delimited and are again designated I, II, and III. The pleurotomariacean gastropods, whose presence delineates gastropod province I, clearly dominate the easternmost exposures of the upper Reedsville and Martinsburg Formations from central Pennsylvania to central Virginia, but are also considerably mixed with the bellerophontacean gastropods of province II in southern Pennsylvania and south-central Virginia. Where this overlap of province I and II faunas takes place there is no noticeable stratigraphic separation of the faunas, but the stratigraphic range of the faunas of province I, the pleurotomariaceans, is much greater than that of the bellerophontaceans of province II which appear to be more confined to the uppermost portions of the upper Reedsville. The bellerophontaceans are also normally limited to the westernmost exposures of the upper Reedsville Formation along this same part of the strike belt. The murchisoniacean gastropods, which constitute gastropod province III, are geographically distinct and not mixed with the dominant northern faunas but appear to occur at the same stratigraphic horizon as the bellerophontaceans of province II, hence occupying the uppermost portions of the upper Reedsville.

TABLE 6. Gastropod faunal provinces. See also Fig. 16.

	Location	Abundant Fauna
I	Central Pennsylvania to central Virginia	Pleurotomariacea *Loxoplocus* (*Lophospira*) *abbreviata* *L.* (*L.*) *perangulata* *Ruedemannia? lirata* *Sinuopea?*
II	South-central Pennsylvania to eastern West Virginia	Bellerophontacea *Plectonotus?* sp. *Bucania* sp.
III	Northern Tennessee	Murchisoniacea *Murchisonia?*

Bivalvia

The north-south zoogeographic pattern outlined by the Upper Ordovician Bivalvia in the central Appalachians is quite similar to that of the Brachiopoda (Fig. 17, cf. Fig. 14). The bivalve faunas are, however, often restricted to the westernmost exposures of the upper Reedsville Formation. As in other instances, three bivalve provinces have been delimited, and each of these is characteristically dominated by two or three abundant species (Table 7).

Bivalve province I occupies much of central Pennsylvania, with only locally abundant nuculoid and actinodontoid bivalve molluscs. The overlap with province II, a diverse assemblage of mussel-like bivalves, in south-central Pennsylvania shows a marked stratigraphic separation of the two faunas (Fig. 18). The species of bivalve province I are found from 100 to 150 feet lower in the section than those of province II. The fauna of bivalve province II shows the greatest number and diversity of the Bivalvia in the central Appalachians. The four dominant bivalve species in province

II are not randomly mixed; rather, they occur in a characteristic stratigraphic order with *Tancrediopsis* and *Ischyrodonta* overlying *Ambonychia* and *Modiolopsis* (Fig. 18). In addition *Modiolopsis modiolaris* dominates bivalve province II in the more easterly exposures in central Virginia; *Tancrediopsis cuneata* and *Ambonychia praecursa* are dominant in south-central Pennsylvania and eastern West Virginia. *Tancrediopsis cuneata* and *Ischyrodonta truncata* are only occasionally found on the same

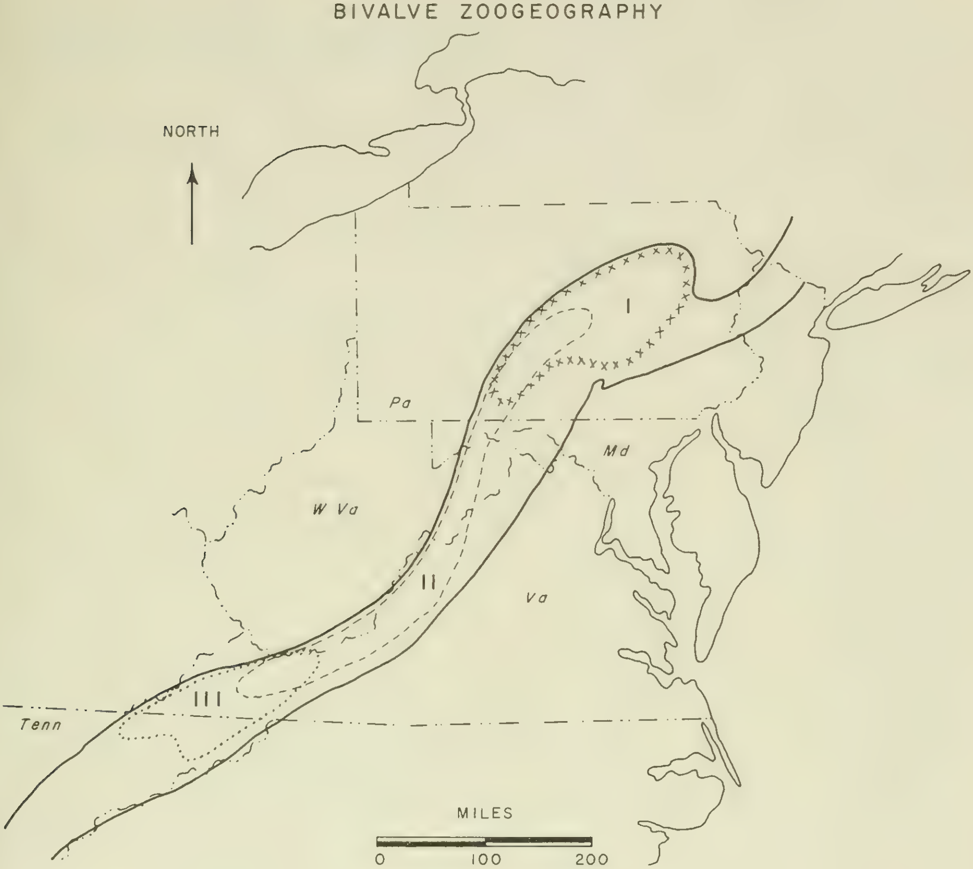


FIG. 17. A generalized outline of the distribution of the most common bivalve mollusc species in the central Appalachian Upper Ordovician. The three major bivalve faunal provinces are:

I. *Lyrodesma poststriatum*
Ambonychia radiata
Ctenodonta? pulchella
Praenucula levata
II. *Tancrediopsis cuneata*
Ambonychia praecursa
Modiolopsis modiolaris
Ischyrodonta truncata
III. *Pterinea* (*Caritodens*) *demissa*

Note as was the case with the brachiopod faunal provinces overlay may not indicate faunal mixing since the faunas are separated stratigraphically, see Fig. 18.

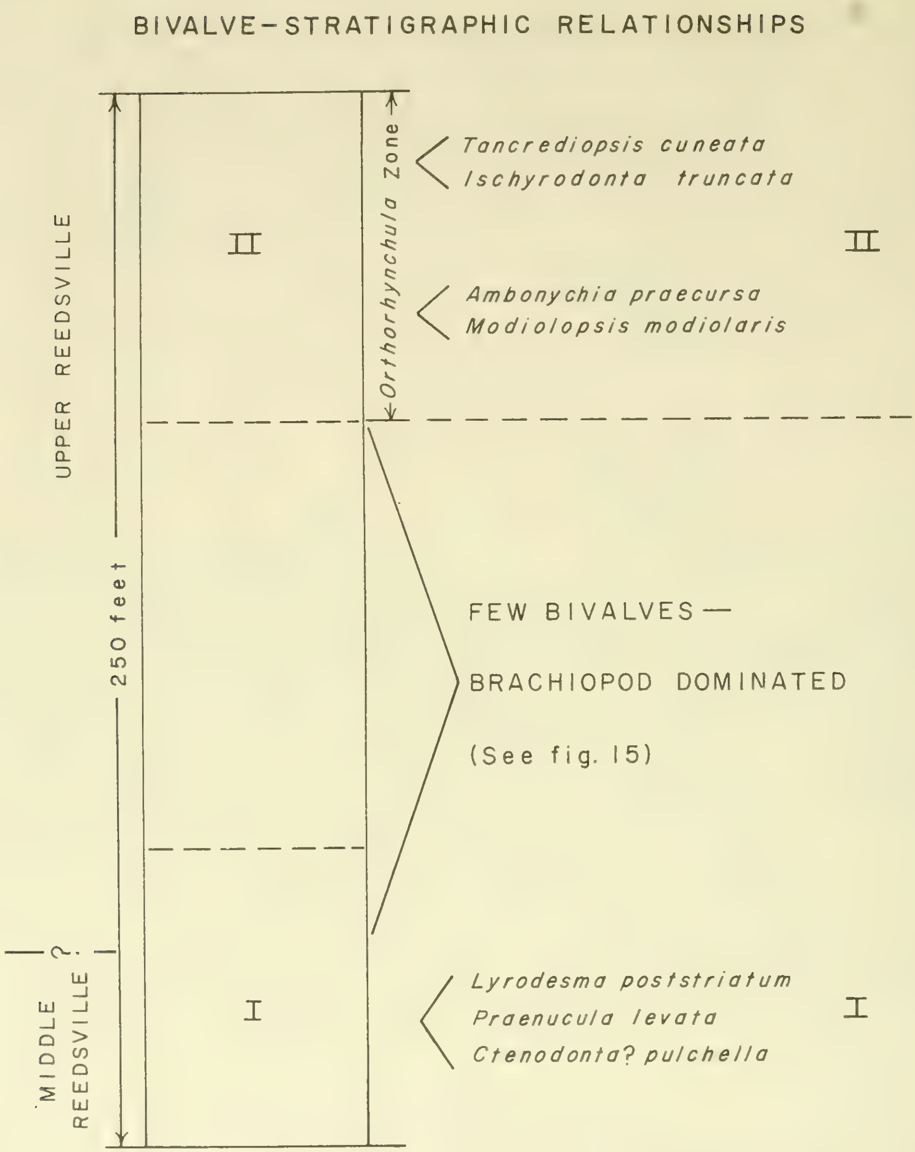

BIVALVE-STRATIGRAPHIC RELATIONSHIPS
UPPER REEDSVILLE
250 feet
MIDDLE REEDSVILLE ?
II
I
Orthorhynchula Zone
Tancrediopsis cuneata
Ischyrodonta truncata
Ambonychia praecursa
Modiolopsis modiolaris
II
FEW BIVALVES—
BRACHIOPOD DOMINATED
(See fig. 15)
Lyrodesma poststriatum
Praenucula levata
Ctenodonta? pulchella
I

FIG. 18. A composite columnar section from the upper and middle(?) Reedsville in south-central Pennsylvania showing a pronounced stratigraphic-faunal separation of bivalve provinces I and II. See Figure 17 for geographic extent of this overlap.

bedding plane, in contrast to the much stronger association between *Ambonychia praecursa* and *Modiolopsis modiolaris*. There is a slight mixing of faunas of provinces II and III in southwestern Virginia, where there is no stratigraphic separation like that between I and II in the north. Bivalve province III is as restricted geographically as province I and shows no greater diversity, but the specimens are more numerous in a series of closely spaced localities. The two dominant species in province III, *Pterinea* (*Caritodens*) *demissa* and *Ambonychia cultrata*, exhibit no consistent stratigraphic separation.

TABLE 7. Bivalve faunal provinces. See also Fig. 17.

	Location	Abundant Fauna
I	Central Pennsylvania	*Lyrodesma poststriatum* *Praenucula levata* *Ctenodonta? pulchella*
II	South-central Pennsylvania to south-central Virginia	*Tancrediopsis cuneata* *Ambonychia praecursa* *Modiolopsis modiolaris* *Ischyrodonta? truncata*
III	Southwestern Virginia and northern Tennessee	*Pterinea (Caritodens) demissa* *Ambonychia cultrata*

PALEOAUTECOLOGY

Each of the twelve systematically segregated faunal provinces discussed in the preceding chapter was shown to be composed of normally less than four abundant genera and/or species. The important point is, however, that particular faunas do outline discernible zoogeographic patterns, and thus provide a basis for the interpretations of the life habits of each of the major taxonomic groups. Furthermore, understanding why these zoogeographic patterns exist in view of the autecology of the component species will provide for the recognition of probable environmental settings. Then by combining the ideas of zoogeography, autecology and the environmental setting, further interpretations of the structure of the Upper Ordovician faunal communities can be made. The discussion of the Upper Ordovician invertebrate communities will be reserved for the succeeding chapter.

BRYOZOA

The most important Bryozoa in the central Appalachian clastic facies are trepostomes, although there are rare fragments of cyclostomes and cryptostomes. Morphologically, the trepostomes are commonly ramose; the branches are either subcylindrical or lobate, flattened plates. The diameter of the lobations is not known to exceed 20 mm, and the cylindrical stems may be as thin as 1 mm. Irregular to hemispherical encrusting growth forms occur in a few localities but are never very numerous. Size differences in the diameters of the branches often may be of secondary taxonomic value at any one locality, but extrapolation of these data to nearby exposures was shown to be unreliable.

Comparison of the growth forms of the trepostomatous bryozoans with those of Recent bryozoans aids in reconstructing a probable environmental setting for these Upper Ordovician specimens. The most common Upper Ordovician clastic-facies forms are most like the Recent adeoniform and vinculariiform zoarial types (Stach, 1936; Lagaaij and Gautier, 1965)*. Lagaaij and Gautier (1965) have recognized these zoarial types off the Rhone delta and have found them widely distributed in 30 to 140 meters of water with mixtures of the two types in 50 to 80 meters of water, an area which can be generally classified as near the boundary between the inner and outer sublittoral — a quiet-water environment.

Lagaaij and Gautier (1965, p. 45) consider the correlation between depth and external morphological type primarily as a reflection of the sensitivity of the bryozoans to sedimentation rate. Maps of species numbers and diversity indicate that most Recent bryozoans are able to tolerate only very moderate to low rates of deposition, and therefore they are abundant only in quiet-water environments away from the delta fronts and inaccessible to sediment-laden currents. The common surface of attachment is a very slightly mobile sand-silt (Lagaaij and Gautier, 1965, p. 52). There is no reason to expect the Upper Ordovician forms to have been more tolerant of high sedimentation rates than modern forms. Recent bryozoans adopt an encrusting form when turbulence increases and the substratum becomes more mobile. Similarly, the Ordovician encrusting bryozoans are found in a coarser, better sorted sandstone. In some stratigraphic sections, increase in the silt/mud ratio is accompanied by a change from the ramose to the encrusting habit within the same genus (Fig. 30).

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*Lagaaij and Gautier (1965, p. 51, text-fig. 24):

Adeoniform — zoarium erect, rigid, lobate, firmly attached to firm substratum. Vinculariiform — zoarium, erect, rigid, subcylindrical branches, attached to firm substratum.

Generic diversity as related to sediment influx along the central Appalachian Late Ordovician shoreline is shown in Figure 19. Bryozoans are generally lacking in south-central Pennsylvania, Maryland and northern Virginia, the most probable source of

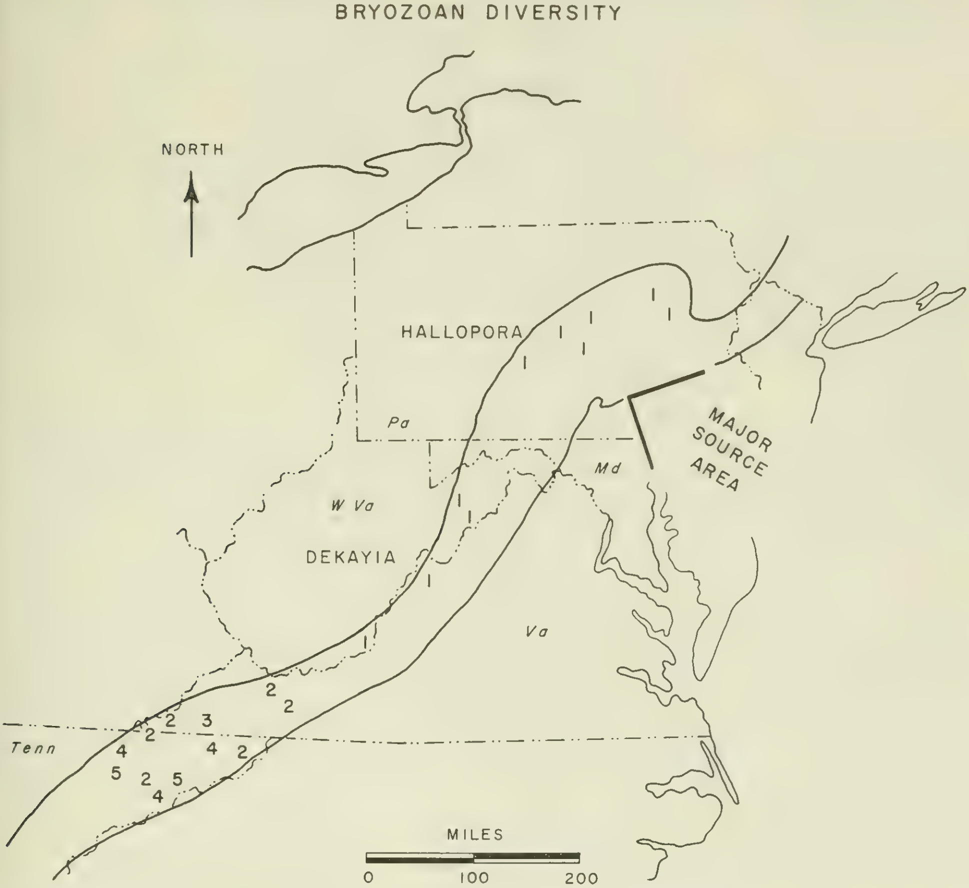


FIG. 19. A generalized outline of trepostomatous bryozoan diversity (genera) in the central Appalachian Upper Ordovician. Of particular note is that the low generic diversity in Pennsylvania, northern Virginia and eastern West Virginia may be directly related to the main source of terrigenous clastic influx during the Late Ordovician.

Numerals refer to number of genera identified at each locality where abundance of the individual genus was greater than 2 on the relative abundance scale.

a major Late Ordovician influx of terrigenous clastics. Immediately to the north and south of this source area, bryozoans are locally common and of the same genus in each locality. In southwestern Virginia and northern Tennessee, well away from the main terrigenous source, many localities have as many as five common genera. The obvious change in sediment type from sands and silts in the north to silty muds and muds in the south and the accompanying increase in bryozoan diversity probably indicate less turbulence and a lower rate of sedimentation in the south.

Figure 20* is a reconstruction of the probable environmental setting of the bryozoans during the Late Ordovician in the central Appalachians. *Dekayia* dominates the nearshore environments in the muddy silts and sands just off the main source area. *Hallopora* is abundant in many environments further offshore. With the increased diversity away from the area of clastic influx, there is a mixing of more bryozoan species, and the faunal composition of particular bryozoan populations is very unpredictable. A substratum of muddy silts or muds instead of coarser clastics is much preferred by the Upper Ordovician trepostomes; the diversity gradient may reflect a general gradient in the rates of sedimentation.

BRACHIOPODA

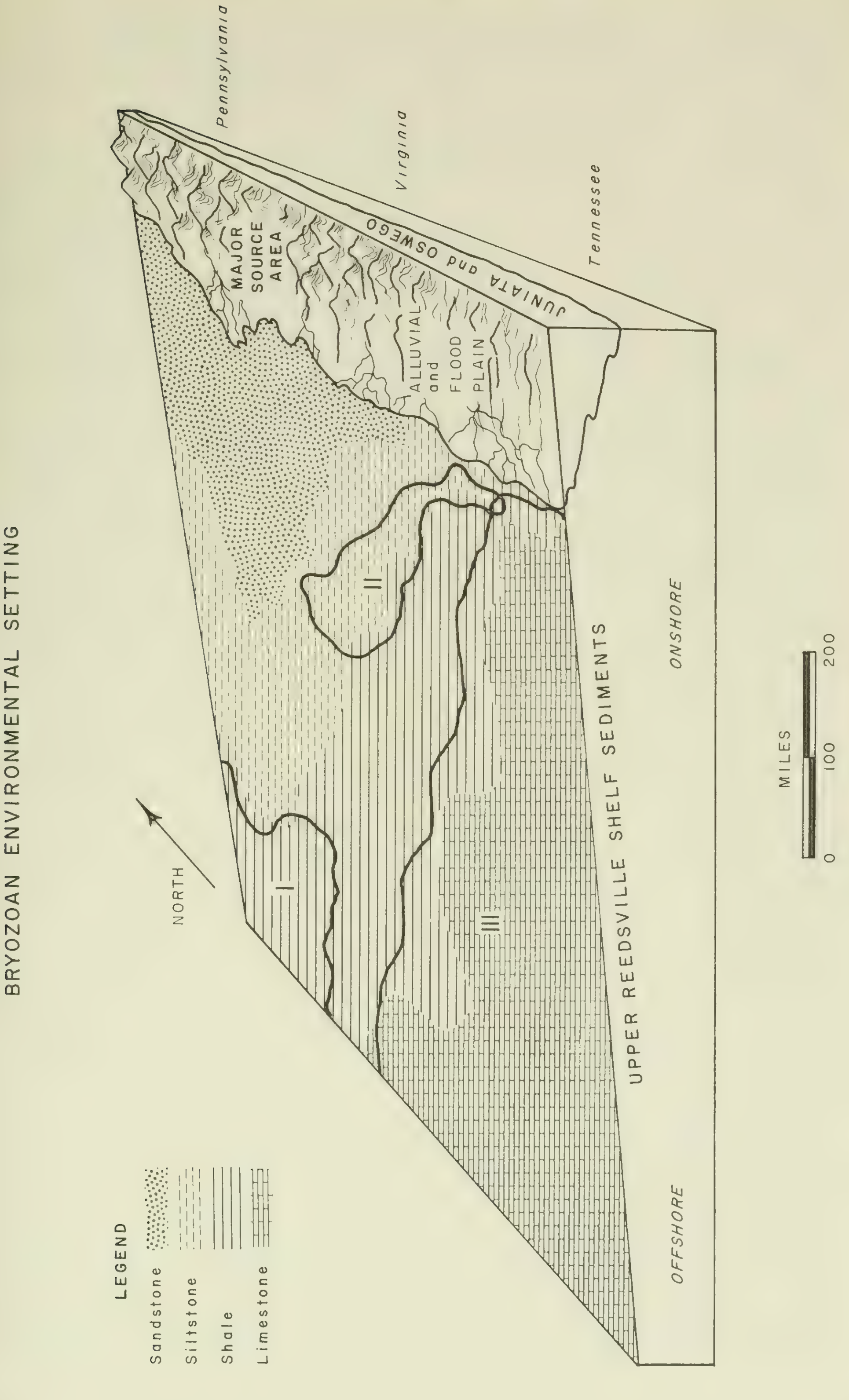
The interpretation of the life habits of the Upper Ordovician brachiopods is hindered by our lack of knowledge of the anatomy and ecology of modern brachiopods. Furthermore, there are no living representatives of the orthids, spiriferids and strophomenids, with the possible exception of the Recent genus *Lacazella* (see Elliott, 1965, p. H857). Some ecological speculations are possible, however, from both living brachiopods and from bivalve molluscs which show morphological and ecological convergence with the brachiopods.

*Figures 20–23 are reconstructions of the probable onshore to offshore Late Ordovician environmental settings within each of the four major taxonomic groups based on the stratigraphic relationships (Figs. 15, 18), present zoogeographic distributions (Figs. 13, 14, 16, 17) and the Late Ordovician sedimentological framework of a prograding depositional regime (Fig. 12). Provincial boundaries as depicted in these figures are entirely interpretational and are not plots of collected distributional data.

FIG. 20. Reconstruction of the Late Ordovician bryozoan environmental setting in the central Appalachians. [See Fig. 13 which is an outline of bryozoan distribution (zoogeography) compiled directly from locality data without environmental interpretations.] This reconstruction, however, combines stratigraphic, sedimentological and ecological interpretations to form a general pattern of onshore to offshore environments occupied by abundant bryozoans. Genera abundant in these three bryozoan faunas:

I. *Hallopora*
II. *Dekayia*
III. *Monticulipora*
Amplexopora
Dekayia
Heterotrypa
Batostomella
Peronopora?
Hallopora

The scale refers to distance along the shore; onshore to offshore exaggeration is approximately ×4.


BRYOZOAN ENVIRONMENTAL SETTING
Pennsylvania
Virginia
Tennessee
MAJOR SOURCE AREA
JUNIATA and OSWEGO
ALLUVIAL and FLOOD PLAIN
I
II
III
NORTH
UPPER REEDSVILLE SHELF SEDIMENTS
ONSHORE
OFFSHORE
MILES
0
100
200
LEGEND
Sandstone
Siltstone
Shale
Limestone

The study of the distribution of marine animals involves salinity, temperature, feeding type and substratum composition. All modern articulate brachiopods are limited to waters of normal marine salinity, and no fossil articulates are known from undoubted brackish-water deposits (Hyman, 1959, p. 520; Rudwick, 1965, p. H211); this indicates that all the central Appalachian Upper Ordovician species, except the linguloid species, were probably restricted to waters of normal marine salinity. By analogy with Recent linguloids, the occurrence of only numerous *Lingula*? probably reflects brackish-water conditions (Craig, 1952, p. 114). Its occasional mixture with *Orthorhynchula linneyi* probably indicates, however, other nearshore normally saline environments. *Lingula*? in the central Appalachians has not been found associated with any articulate brachiopod other than *Orthorhynchula linneyi.*

The sparse information concerning Ordovician paleotemperatures is of questionable significance. Spjeldnaes (1960), Opdyke (1962), Irving (1964) and Whittington (1966) have presented lithologic, paleomagnetic and faunal data in the reconstruction of the climatic zones and geography of the Ordovician. The paleomagnetic data presented by Irving (1964, p. 202), the evaporite-lithologic data of Opdyke (1962, p. 57, fig. 10) and the faunal data of Spjeldnaes (1960, p. 66, fig. 5A) and Whittington (1966, p. 730, fig. 16) are all consistent with a paleoequator that describes an arc bisecting the United States from Wisconsin to Texas. These data indicate a subtropical or warm temperate environment for eastern North America during the Late Ordovician. Whittington (1966, p. 731), working primarily with Ordovician trilobites, explains the extremely diverse Upper Ordovician faunas as reflecting the warmest of all Ordovician climates, probably responding to the direction and intensities of ocean currents much more than to substratum.

Recent brachiopods, with the exception of *Lingula,* appear to prefer cooler or deeper waters (Hyman, 1959, p. 594–599), but this may be a consequence of the general reduction in numbers, diversity, and bathymetric distribution of the phylum. The existence of local current patterns (McBride 1960, 1962) during deposition of the Martinsburg and Reedsville Formations must also be considered. Upwelling of colder, deeper basinal waters onto the Ordovician shelf and possible longshore currents could drastically influence the mean annual surface temperature patterns. Bayer (1967, p. 421), working with similar Mid-Continent Upper Ordovician orthid and strophomenid brachiopod faunas (cf. brachiopod faunal province I), considered the large number of individuals of relatively few species characteristic of cooler waters. We have little knowledge of the actual temperature and current controls that may have influenced the distribution of these central Appalachian Upper Ordovician brachiopods, although the central Appalachian shelf phosphates suggest a deep-water upwelling as the source of this phosphate.

Brachiopods are lophophorate suspension feeders. They do not filter in the same way as some of the filter-feeding bivalve molluscs, which sieve particles through their gill filaments. They feed by producing ciliary currents which bring a constant stream of water over the lophophore (Atkins, 1960; Atkins and Rudwick, 1962). Recent brachiopods are able to adjust the velocity of the feeding current by altering ciliary beat. Food gathering in brachiopods is more nearly equivalent to the filtering mechanism used by bryozoans, polychaetes, or crinoids. Food particles are perhaps removed from the water by trapping by a mucous layer on the lophophore (Chuang, 1956), but the mechanism of retention of food particles is not well understood (Jørgensen, 1966). There is apparently no sorting of the particles either according to shape or size (Jørgensen, 1966; for evidence of a different kind of sorting mechanism in fossil brachiopods see Ager, 1963, p. 58–59), or according to value as food (Rudwick, 1962; Hyman, 1959, p. 589–590).

To secure the optimum quantities of suspended organic matter, the mechanism of suspension feeding in the brachiopods may have required less current activity than necessary for the bivalves; therefore, differences in feeding methods may have resulted in the adaptation of brachiopods to life in areas where most epifaunal bivalve molluscs had been excluded. However, the rhynchonellid brachiopod *Orthorhynchula linneyi* is most abundant in an area where there are numerous mussel-like *Ambonychia praecursa, Modiolopsis modiolaris* and *Ischyrodonta truncata* nearby. The orthid *Hebertella sinuata* and the spiriferid *Zygospira recurvirostra* are also occasionally found with abundant *Pterinea* (*Caritodens*) *demissa* and locally abundant species of *Ambonychia* and *Modiolopsis*. Only the northern brachiopod fauna (faunal province I), dominated by the strophomenids *Rafinesquina "alternata"* and *Sowerbyella* (*Sowerbyella*) *sericea* and the dalmanellid *Onniella multisecta,* lacks an extensive epifaunal bivalve molluscan element. Here it is possible that the actual mechanisms of feeding, or a more efficient metabolism, of these brachiopod species could give them a selective advantage over the bivalves, but this is speculative.

The substratum, the only major environmental parameter for which we have any direct evidence in the central Appalachian Upper Ordovician, is particularly significant because of the sessile benthonic habit of the brachiopods. It appears that the nature of the substratum may have direct control over the pattern of brachiopod distribution, and also may determine the localization of species within the broader pattern of regional distribution. The rhynchonellids are most abundant in the coarse silts and sands. The strophomenids, dominant in the north, are more common in muddy silts, whereas the orthids, both in the north and in the south, appear in silty muds, muds and lime muds. The spiriferids show a preference for extremely fine sediments and are most abundant in the lime muds. Each of these brachiopods may also at times be found in other types of substratum. In addition, it appears that sedimentation rates and turbulence, as well as the substratum, play a major role in geographic distribution.

Rudwick (1965, p. H212) suggested that while brachiopods may tolerate moderate turbulence, they are less tolerant of actual sediment influx. Living brachiopods can interrupt the feeding process, adjust and reverse their ciliary beat to reject too large quantities of suspended particles and if necessary close their valves for several hours. Unlike some bivalve molluscs, they neither can maintain this complete shutdown for long periods nor (with the exception of linguoids) can they change their position if sedimentation becomes too rapid. According to Hyman (1959, p. 588) brachiopod powers of adjusting the feeding currents were a direct adaptation to life on "muddy" substratum where high turbidity occurs intermittently.

The segregation of the brachiopod faunas in the central Appalachian Upper Ordovician appears to be the result of the location and rate of the terrigenous clastic influx. The environmental setting of the brachiopods would begin at an early stage in the development of the source areas east of southern Pennsylvania and northern Virginia, when the clastic influx was low and the sedimentation rate low enough to permit the development of a major brachiopod shelf fauna, faunal provinces I and III. With increased influx the shoreline prograded westward and distinct nearshore and offshore brachiopod components developed. *Lingula*? and *Orthorhynchula linneyi,* faunal province II, were more able to cope with the nearshore increase in terrigenous influx, but never thrived to the south in a presumably less turbid nearshore environment. The dominance of the nearshore faunas of province II reflects a dynamic change in the environmental conditions along the shoreline. Figure 21 is a representation of the environmental setting of the Late Ordovician brachiopod faunas during the development of the Oswego bar and barrier deposits in south-central Pennsylvania and eastern West Virginia.

The central Appalachian strophomenids, orthids and spiriferids probably lived in an environment where the average sedimentation rate was low, but where the sporadic occurrence of a high sedimentation rate probably took the form of sudden local turbidite flows. The brachiopods may have been able to adapt, to some extent, to these periodic sediment influxes, but localized populations may have been eliminated with subsequent repopulation from some other source. Recurrent orthid-strophomenid faunas in the Mid-Continent Upper Ordovician have been recently described by Bayer (1967). The orthid-strophomenid populations, decimated by increased rates of sedimentation, re-established themselves when sedimentation rates decreased. Since the central Appalachian linguloids and rhynchonellids existed in areas of high sedimentation, the possible vertical mobility of the linguloids was apparently an effective adaptation of *Lingula*?, but the morphological adaptations of *Orthorhynchula linneyi* are obscure. A long, stout pedicle and globose, sulcate form may have provided the necessary protection against complete annihilation of large segments of the population during periods of rapid sediment influx. Again the stratigraphic-sedimentological record seems to support an irregular rate of sedimentation. The transport of nearshore sands along the coast may have been sufficiently sporadic to permit the establishment of large rhynchonellid populations. The morphological adaptations of individual species are considered in more detail in the systematic discussion of each taxon.

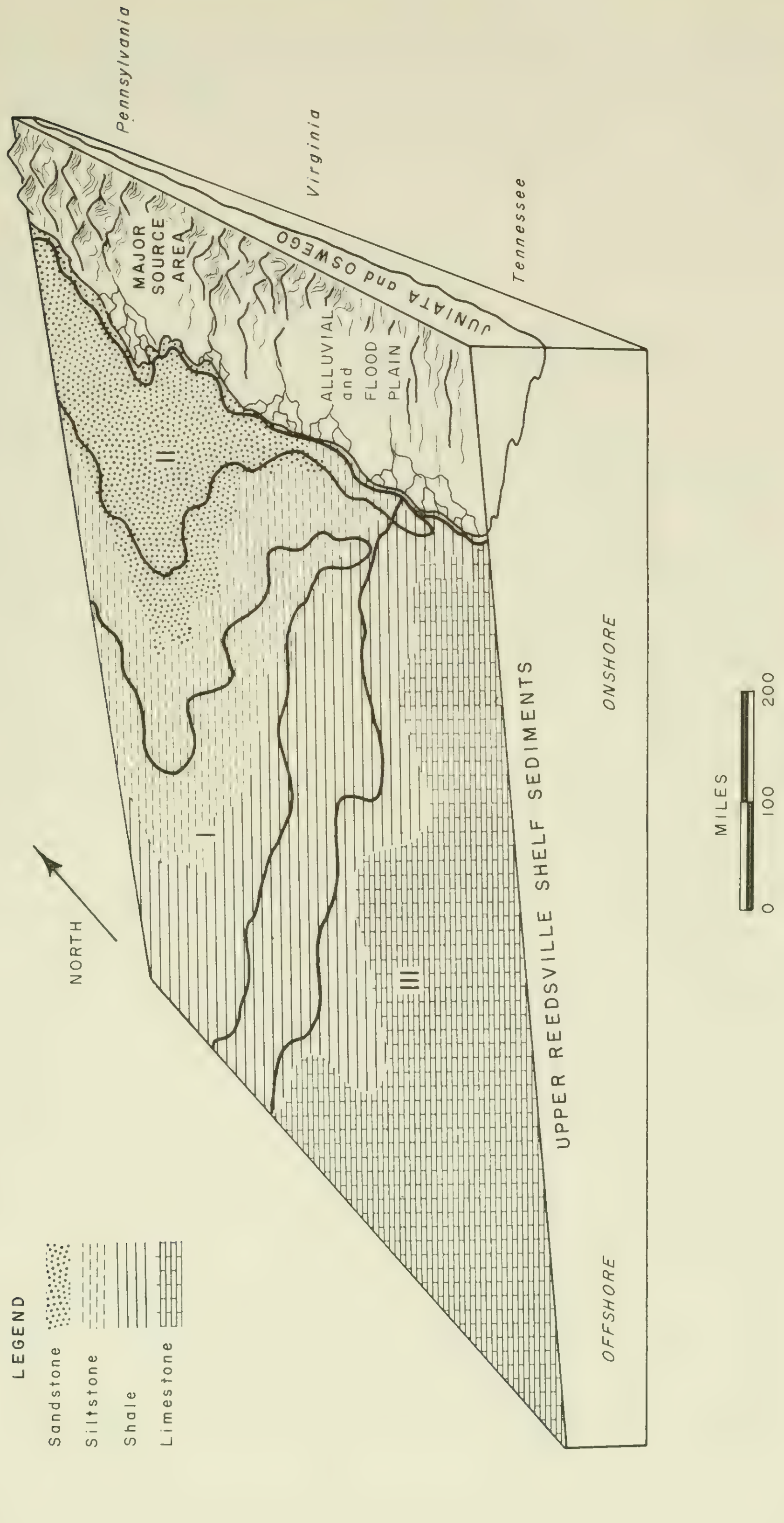
Hyman (1959, p. 591) stated that no combination of species of Recent brachiopods has been shown to recur in a predictable way in Recent level-bottom associations, although as sessile animals the brachiopods would be expected to have some common associations with other sessile, sedentary animals. Like most modern brachio-

FIG. 21. Reconstruction of the Late Ordovician brachiopod environmental setting in the central Appalachians. [See Fig. 14 which is an outline of brachiopod distribution (zoogeography) compiled directly from locality data without environmental interpretations.] This reconstruction, however, combines stratigraphic, sedimentological and ecological interpretations to form a general pattern of onshore to offshore environments occupied by abundant brachiopods. Species abundant in these three brachiopod faunas:

I. *Rafinesquina "alternata"*
Sowerbyella (Sowerbyella) sericea
Onniella multisecta
Zygospira modesta
II. *Orthorhynchula linneyi*
Lingula?
III. *Zygospira recurvirostra*
Hebertella sinuata

The scale refers to distance along the shore; onshore to offshore exaggeration is approximately ×4.

BRACHIOPOD ENVIRONMENTAL SETTING


Pennsylvania
Virginia
Tennessee
MAJOR SOURCE AREA
JUNIATA and OSWEGO
ALLUVIAL and FLOOD PLAIN
II
I
III
NORTH
UPPER REEDSVILLE SHELF SEDIMENTS
ONSHORE
OFFSHORE
MILES
0
100
200
LEGEND
Sandstone
Siltstone
Shale
Limestone

pods, the central Appalachian Upper Ordovician forms appear to have been gregarious (see Mattox, 1955, for a Recent example). Recent brachiopods have a pelagic larval stage that lasts only a few hours. Although it appears that the powers of larval dispersal are limited (Hyman, 1959, p. 590; Rudwick, 1965), I doubt that the vagaries of larval settling alone could account for the absence of a species from an apparently suitable substratum.

GASTROPODA

An interpretation of the life habits and environmental setting of the Upper Ordovician bellerophontacean and pleurotomariacean gastropods can be made by inference from the Recent Pleurotomariacea; there are no living Bellerophontacea. Batten (1958, p. 169) and Yochelson (1960, p. 215) reviewed the sparse ecologic data, derived mainly from the work of Yonge (1947), dealing with pleurotomariaceans. Archaeogastropods require a firm substratum and low turbidity. Their bipectinate, aspidobranch gills are easily fouled because their ciliary action is not capable of freeing quantities of mud from the gill filaments. Batten (1958) also noted that the majority of recent Pleurotomariacea live at depths between 50 and 200 fathoms and seem better adapted to colder, possibly deeper waters with some, however, tolerating brackish-water conditions. All are presumably macrophagous herbivores, browsing on algal fronds or collecting algal material from the substratum surface (Graham, 1955, p. 149).

The Upper Ordovician pleurotomariacean gastropods, faunal province I, are most abundant in fine sandstones and siltstones. The stratigraphic and sedimentological evidence indicates that they existed farther from shore than the bellophontaceans of faunal province II. The characteristic local patchiness of province I species may reflect the irregular distribution of detrital plant material by gentle currents moving over the substratum. Since the influence of water temperature is difficult to ascertain, I find it difficult to attribute the distribution of *Loxoplocus* (*Lophospira*) solely to current patterns.

The most abundant bellerophontid gastropod, *Plectonotus*? sp. of faunal province II, is found in the area where the upper Reedsville silts and sands are transitional upward into the cross-bedded sands and organic-rich muds of the lower Oswego. *Plectonotus*? sp. is not commonly associated with the pleurotomariaceans, though both types of gastropods inhabit silts of the same general texture. Seemingly this combination of Reedsville-Oswego lithologies could be a major influence on the distribution of abundant plectonotid species. The organic-rich black muds of the lagoons may be protected areas of Ordovician algal stands; the browsing of the bellerophontid on the algal fronds would probably place it above any sporadic turbid currents which would tend to clog its delicate ctenidia. The low pH of the organic-rich muds probably prevented the preservation of the calcareous shells of this species, if indeed they did inhabit this region; but shells were preserved farther off-shore, clumped together and often surrounded by a sediment with more organic matter than the surrounding rock. *Plectonotus*? sp. could have been rafted out into the deeper marine waters on algal fronds during periods of high water, or even have been maintained on a firm substratum if there had been an adequate supply of plant detritus near the site of preservation. The patchiness or clumping of the bellerophontids, which is also characteristic of the pleurotomariaceans, could result from a highly localized food source, such as algal material concentrated in shallow basins or hollows between shoals. These also appear to be the areas of the highest concentration of phosphate grains, many forming as internal molds of *Plectonotus*? sp.

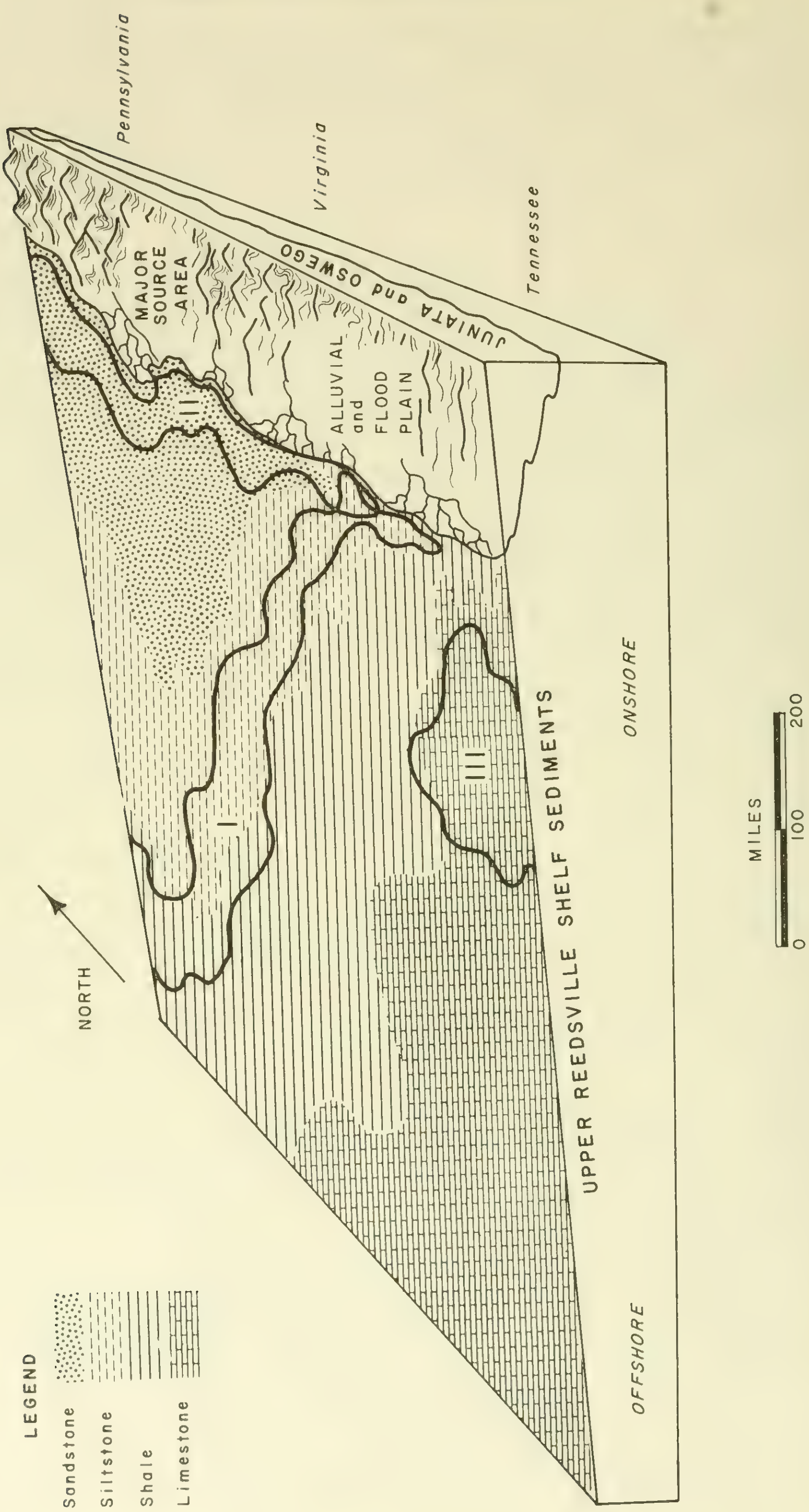
In faunal province III the murchisoniid gastropods are confined exclusively to the Upper Ordovician carbonate muds of northern Tennessee, in contrast to the silty substratum of the bellerophontid and pleurotomariid provinces to the north. Figure 22 reconstructs the environmental setting of the gastropod fauna along the Late Ordovician central Appalachian shoreline. Cox and Knight (1960, p. I290) describe murchisoniid morphology. These snails have the inhalant siphon characteristic of the mesogastropods, although they retain features characteristic of the archaeogastropods. Recent Pleurotomariacea can exist only in clear waters and on a firm substratum. As Lower Paleozoic pleurotomariacean populations gradually expanded onto a muddier substratum, individuals possessing a ctenidial structure from which mud particles could be more easily removed would have had a selective advantage over those individuals whose powers of removing mud particles from the ctenidia was limited. Along with the development of monopectinate ctenidia, evolutionary changes advantageous to the mud dweller would be the development of an extensible inhalant siphon and the modification of the foot to allow the ancestral mesogastropod to move through or over the soft substratum. Thus the clear separation of the northern bellerophontid and pleurotomariid gastropod faunas from the southern murchisoniid gastropods was probably influenced by substratum type.

BIVALVIA

The life habits and environmental setting of the central Appalachian Upper Ordovician bivalves may be inferred by comparison with analogous modern bivalve families. Recent nuculoids, mussels and pterioids give some clues as to the ecology of the Upper Ordovician species, but uncertainties exist because only a few Recent studies have gathered enough data for an adequate reconstruction of ancient autecology. Also, some abundant central Appalachian Upper Ordovician bivalve genera — for example, *Lyrodesma*—permit few comparisons with any known Recent species. As pointed out in the discussion of the Brachiopoda, four of the most critical factors controlling the distribution of marine animals are salinity, temperature, feeding type and substratum. These environmental variables, singly or in combination, control the distribution of fossil and Recent Bivalvia.

Most Upper Ordovician bivalve species appear to have lived in waters of normal marine salinity, as they either are associated with species that are commonly accepted as being normally marine (e.g., articulate brachiopods) or have Recent morphological analogues that live in waters of normal marine salinity. One possible euryhaline species is the nuculoid *Tancrediopsis cuneata,* which commonly occurs with numerous specimens of *Lingula*? in the upper parts of the upper Reedsville Formation (see Figs. 7 and 29). Here the upper Reedsville muddy siltstones and sandstones are interbedded with the bar-barrier deposits of the Oswego-like sandstones. *Tancrediopsis cuneata* may have been able to tolerate periods of fresh-water influx and

GASTROPOD ENVIRONMENTAL SETTING


Pennsylvania
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JUNIATA and OSWEGO
MAJOR SOURCE AREA
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ONSHORE
OFFSHORE
NORTH
MILES
0
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200
LEGEND
Sandstone
Siltstone
Shale
Limestone

accompanying changes in salinity. Parker (1960, p. 310) lists two species of *Nuculana,* a Recent nuculoid, as occurring in an enclosed lagoonal environment along a considerable length of the northern coast of the Gulf of Mexico. *Nuculana* was found on both sides of the prograding Mississippi deltaic complex and apparently is tolerant of changes in salinity, temperature, and substratum type. The central Appalachian *Tancrediopsis cuneata* could also have been adapted to a variety of environmental conditions; it is found in sediment types ranging from muds to silts and shows a considerable north-south distribution on both sides of the area of maximum terrigenous influx. The only other possible exception to a normal marine existence may be found in the few isolated patches of abundant *Modiolopsis modiolaris* along the eastern exposures of the Reedsville Formation in central Virginia. These Upper Ordovician mussel-like bivalves may have occupied an intertidal silt-mud flat situation like that inhabited by the related *Modiolus rectum,* a common species along the west coast of the United States.

Temperature is also likely to have controlled the distribution of the central Appalachian Upper Ordovician Bivalvia, but evidence for temperature variations is indirect. Kinne (1963), Read (1964) and Hall (1964) have reviewed and summarized a great deal of information pertaining to the distribution and physiological adaptations of the modern bivalves as a function of temperature. Hutchins' (1947) classic paper outlines the strict temperature tolerances that exist in Recent shelf invertebrates. Well-defined latitudinal boundaries of particular associations of Recent bivalves have proved extremely useful in ecological interpretations of Tertiary and Quaternary bivalves. Woodring, Bramlette and Kew (1946), Durham (1950) and Valentine (1961) have shown distinct isothermal control of the distribution of species through time. The north-south temperature gradient of the Upper Ordovician has been surveyed in the discussion of brachiopod life habits, and it appears that the central Appalachian Upper Ordovician shoreline was located somewhere between 10 and 20 degrees of latitude with reference to the paleoequator (see Opdyke, 1962, p. 57, fig. 10), a subtropical or warm temperate environment.

Temperature control of the Upper Ordovician Bivalvia may have been effected either by local current patterns or by a broader onshore-offshore change in temperature. Local current patterns have been documented from previous sedimentological studies in the Reedsville and Martinsburg Formations (McBride, 1960, 1962) and

FIG. 22. Reconstruction of the Late Ordovician gastropod environmental setting in the central Appalachians. [See Fig. 16 which is an outline of gastropod distribution (zoogeography) compiled directly from locality data without environmental interpretations.] This reconstruction, however, combines stratigraphic, sedimentological and ecological interpretations to form a general pattern of onshore to offshore environments occupied by abundant gastropods. Species abundant in these three gastropod faunas:

I. *Loxoplocus* (*Lophospira*) *abbreviata*
    L. (*L.*) *perangulata*
    L. (*L.*) *ventricosta*
    Ruedemannia? lirata
    Sinuopea?
II. *Plectonotus?* sp.
    Bucania sp.
III. *Murchisonia?*

The scale refers to distance along the shore; onshore to offshore exaggeration is approximately ×4.

could result from colder upwellings along the shelf. The sharp separation of the species of faunal provinces I and II may reflect an onshore-offshore temperature gradient. The species of faunal province I appear, from stratigraphic and sedimentological evidence, to occupy an outer sublittoral environment; the characteristic patchy distribution of *Lyrodesma poststriatum* may reflect localized colder currents on the shelf. The species in faunal provinces II and III, predominantly inner sublittoral types, may have adapted to a less localized, longshore, warmer isothermal pattern that extended almost the entire length of the central Appalachains. Figure 23 is a diagram of the bivalve species as they were probably distributed during the development of the Oswego bar and lagoonal deposits.

The three main feeding types of most Recent species of Bivalvia are: infaunal deposit or detritus feeders, epifaunal suspension feeders, and infaunal, usually siphonate, suspension feeders. All three feeding types are represented in the central Appalachian Upper Ordovician. Epifaunal suspension feeders dominate the Upper Ordovician, whereas an infaunal suspension feeding habit, which is very common in Recent bivalves, probably existed in only one species, *Lyrodesma poststriatum* (Table 8). The infaunal deposit feeding habit is summarized in a paper by Yonge (1939) on the Recent protobranch bivalves. The Recent genera *Nucula* and *Solemya* correspond very closely to the Ordovician *Tancrediopsis cuneata, Ctenodonta? pulchella*

TABLE 8. Upper Ordovician Bivalve Feeding Types

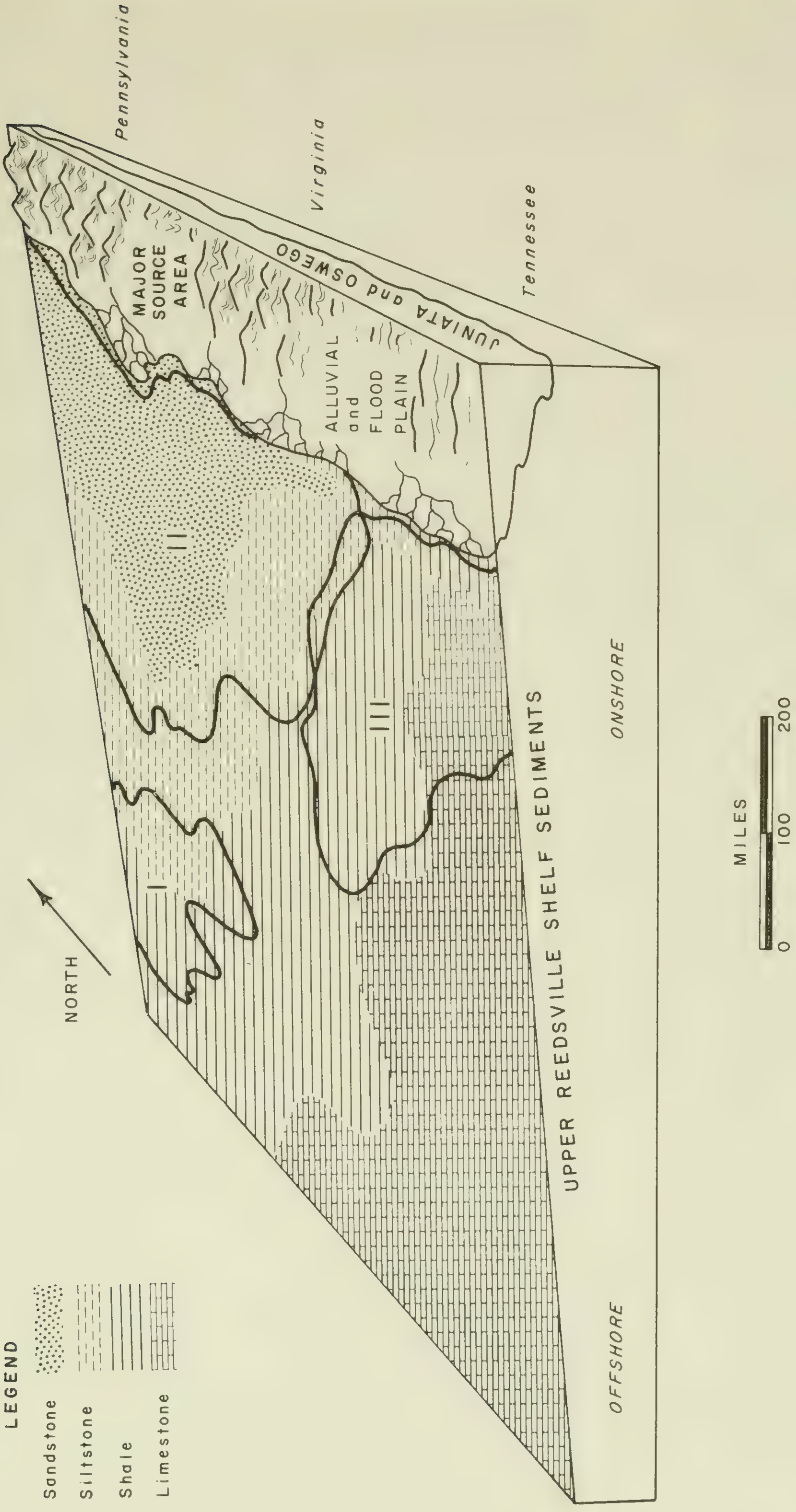
Infaunal		Epifaunal
Deposit	Suspension	Suspension
Tancrediopsis cuneata^2	*Lyrodesma poststriatum*^{1}	*Ambonychia praecursa*^{2}
Praenucula levata^1		*Modiolopsis modiolaris*^{2}
Ctenodonta? pulchella^1		*Ischyrodonta truncata*^{2}
		Ambonychia cultrata^3
		Pterinea (Caritodens) demissa^3

Numbers refer to bivalve faunal provinces (Fig. 17); 1 = offshore, 2 and 3 = onshore. This chart of Upper Ordovician bivalve feeding types emphasizes the fact that bivalve associations are dominated by either infaunal deposit feeders or epifaunal suspension feeders. A reconstruction of the bivalve environmental setting (Fig. 23) shows a pronounced increase in the numbers and diversity of infaunal species from onshore to offshore.

FIG. 23. Reconstruction of the Late Ordovician bivalve environmental setting on the central Appalachians. [See Fig. 17 which is an outline of bivalve distribution (zoogeography) compiled directly from locality data without any environmental interpretations.] This reconstruction, however, combines stratigraphic, sedimentological and ecological interpretations to form a general pattern of onshore to offshore environments occupied by abundant bivalve molluscs. Species abundant in these three bivalve faunas:

I. *Lyrodesma poststriatum*
Praenucula levata
Ctenodonta? pulchella
II. *Ambonychia praecursa*
Modiolopsis modiolaris
Tancrediopsis cuneata
Ischyrodonta truncata
III. *Ambonychia cultrata*
Pterinea (Caritodens) demissa

The scale refers to distance along the shoreline; onshore to offshore exaggeration is approximately ×4.


BIVALVE ENVIRONMENTAL SETTING

Pennsylvania
Virginia
Tennessee
JUNIATA and OSWEGO
MAJOR SOURCE AREA
ALLUVIAL and FLOOD PLAIN
II
III
I
NORTH
UPPER REEDSVILLE SHELF SEDIMENTS
ONSHORE
OFFSHORE
MILES
0
100
200
LEGEND
Sandstone
Siltstone
Shale
Limestone

and *Praenucula levata*; all of these were presumably deposit feeding bivalves. They occupy a number of diverse environments, as do Recent nuculoid species. The few *Nuculites* found in the central Appalachian Upper Ordovician are also members of the infaunal deposit feeding group, but more closely resemble the Recent genus *Nuculana.*

Epifaunal suspension feeders, dominant in the central Appalachian Upper Ordovician, represent the most important type of bivalve feeding in early Paleozoic time. Though epifaunal suspension feeding bivalves are numerically somewhat less important today than infaunal ones, the feeding habits of various species of *Crassostrea, Ostrea* and *Mytilus* have been carefully studied. Graham (1949) summarized many of the bivalve feeding types and supplemented the previously reported data with his analysis of the contents of the bivalve stomach. The effects of various types and concentrations of micro-organisms on the feeding habits and pumping abilities of the epifaunal suspension feeders have been the subject of a few recent investigations (Davids, 1964), but the data is incomplete and of only limited use. There are numbers of epifaunal Bivalvia in the Lower Paleozoic living with some abundant brachiopod species and seemingly in direct competition with the Brachiopoda, which feed similarly. The possible adaptive advantages of the Bivalvia which allowed them to dominate the nearshore, more turbulent environments or, conversely, those which may explain the superiority the Brachiopoda had over the epifaunal Bivalvia in quieter sublittoral environments are not known (Figs. 21 and 23 show the offshore area limitations of the Bivalvia as compared to the Brachiopoda). Brachiopod diversity increases noticeably in the less turbulent, presumably offshore waters, whereas the epifaunal suspension feeding bivalves are much more diverse in a current-influenced, nearshore environment. Mechanisms for dealing with a shifting substratum thus may have been more effective in the Bivalvia than in the Brachiopoda, something that needs further study in modern environments.

The infaunal suspension feeder, a very important feeding type in many Recent environments, is rare in the Lower Paleozoic and is represented only by *Lyrodesma poststriatum* in the central Appalachian Upper Ordovician. The presence of the pallial sinus in the genus *Lyrodesma* was first figured by Ulrich (1893, pl. 47, fig. 9), and I have collected specimens from the central Appalachians that show an equally well-defined sinus. The evolutionary significance of this scattered, but locally abundant, infaunal siphonate bivalve is uncertain. It seems very likely, however, that *Lyrodesma* did not give rise to the later prolific siphonate fauna, but was rather a short-lived offshoot with no descendants. Newell (1965, p. 19) lists the Family Lyrodesmatidae as a questionable member of the trigonids, and Babin (1966, p. 304, fig. 26) shows *Lyrodesma* as a possible ancestor of the genus *Modiolopsis.* But both these interpretations appear to be unlikely with recognition of the distinct pallial sinus.

The central Appalachian Late Ordovician substratum is the major environmental parameter for which direct evidence is available. Recent studies have stressed the importance of a suitable substratum for the settling of pelagic larvae of benthic invertebrates (Wilson, 1952; Thorson, 1957); and Purdy (1964) summarized the abundance, diversity and distribution of marine invertebrates as a function of substratum type. Carey (1965), working off the coast of Oregon, Sanders (1958) in Buzzards Bay, and Craig and Jones (1966) in the Irish Sea have demonstrated the close correlation between the diversity and abundance of epifaunal and infaunal invertebrates, including bivalves, as related to substratum. Generally, infaunal deposit feeders are most common in the more organically rich, finer-grained sediments. The coarser silt and sand environments are dominated by epifaunal suspension feeders. As Carey (1965, p. 100) has stressed, although there is always a complex of factors at work, particle size of sediment generally decreases with distance from shore, with an accompanying increase in the number of deposit feeding organisms. Savilov (1959), working in the northern Okhotsk Sea, found that a replacement of one feeding type by another was related to distance from shore and substratum type. In the Ordovician, the substratum differences probably account for some of the patterns of bivalve distribution in certain parts of the central Appalachians. The changes in the bivalve species among the three faunal provinces interpreted in the light of these Recent distributions are as follows: The epifaunal suspension feeders dominate the silt and muddy silt nearshore environments, but there is a noticeable decrease in numbers and diversity from province II to province III, with an accompanying decrease in the particle size of the sediment. The presumably offshore faunal province I, abundant in the fine silts and muds, shows a higher percentage of infaunal detritus feeders than the other two nearshore provinces. Savilov (1959) states that in Recent environments suspension feeders predominate in shallow waters whereas infaunal detritus feeders dominate offshore muddy silts.

Thus it can now be shown that the twelve systematically segregated faunal provinces each contain species that are not only ecologically compatible within the provinces themselves, but also provide evidence for the definition of distinct marine shelf environments. These environmental interpretations are consistent for those bryozoan, brachiopod, gastropod and bivalve faunal provinces that are superposed without stratigraphic separation (Figs. 20-23; refer also to Figs. 13, 14, 16 and 17). Furthermore this allows for the synthesis of this data into benthic marine communities that are composed of a variety of taxonomic groups and that occupied particular environmental regimes. The following chapter considers this provincial synthesis.

APPALACHIAN UPPER ORDOVICIAN FOSSIL COMMUNITIES

In the preceding discussion of zoogeography and autecology of the Upper Ordovician faunas it is evident that systematically segregated bryozoan, brachiopod, gastropod and bivalve faunas are not isolated from one another, but rather are closely interrelated geographically and stratigraphically. Consistent and recurrent associations of species among the twelve faunal provinces has led to the recognition of three main faunal associations, termed communities; these are outlined in Table 9. Two numerically less significant taxa, the crinoids and trilobites, are also included in Table 9, though neither of these taxa has been treated in detail in this study.

The three communities are composed of groups of species, all of which show a high degree of affinity and a pronounced tendency to recur together throughout the Upper Ordovician strata (Table 3; the recurrences are based on those species which show a relative taxonomic density index of 3 or more). This consistent association of certain species was the basis of Petersen's (1914) concept of a marine bottom community, a concept which is accepted by most marine ecologists today (see Jones, 1950; Thorson, 1957; Valentine, 1961; Fager, 1963; and Speden, 1966), and was employed by Johnson (1962) in his study of Mid-Continent Pennsylvanian assemblages. Each Late Ordovician community is named for its most conspicuous and co-dominant species. The communities are as follows (the specific designation is omitted throughout the remainder of the text):

1. *Sowerbyella sericea–Onniella multisecta* Community
2. *Orthorhynchula linneyi–Ambonychia praecursa* Community
3. *Zygospira recurvirostra–Hebertella sinuata* Community

The communities are subdivided into seven multi-species populations, also on the basis of consistent species associations and recurrence (see again Table 3; as before, the species considered in the recurrence are those whose density index is 3 or more at any one locality). The communities and populations are similarily defined but the latter are more restricted geographically and stratigraphically; clustering of particular species takes place within the overall community structure and is believed to reflect more localized environmental conditions. Table 10 outlines the seven multi-species populations composing these three Late Ordovician communities. The populations are:

TABLE 9. The Late Ordovician Faunal Communities: *Sowerbyella–Onniella*, *Orthorhynchula–Ambonychia*, and *Zygospira–Hebertella*, each based on a recurrent association of the species listed. (See also Table 3).

Faunas	Bryzoans	Brachiopods	Gastropods	Bivalves	Trilobites	Crinoids
Sowerbyella–Onniella Community	*Hallopora*	*Rafinesquina* "*alternata*" *Sowerbyella sericea* *Onniella multisecta* *Zygospira modesta*	*Loxoplocus* (*Lophospira*) *abbreviata* *L.* (*L.*) *perangulata* *L.* (*L.*) *ventricosta* *Sinuopea?* *Ruedemannia? lirata*	*Lyrodesma postriatum* *Praenucula levata* *Ctenodonta? pulchella*	*Isotelus* *Flexicalymene* *Cryptolithus*	crinoid columns
Orthorhynchula–Ambonychia Community	*Dekayia*	*Orthorhynchula linneyi* *Lingula?*	*Plectonotus?* sp. *Bucania* sp.	*Tancrediopsis cuneata* *Ambonychia praecursa* *Modiolopsis modiolaris* *Ischyrodonta truncata*	Very rare	Very rare
Zygospira–Hebertella Community	*Monticulpora* *Dekayia* *Batostomella* *Amplexopora* *Hallopora* *Heterotrypa* *Peronopora?*	*Hebertella sinuata* *Zygospira recurvirostra*	*Murchisonia?*	*Pterinea* (*Caritodens*) *demissa* *Ambonychia cultrata*	Very rare	Very rare

- *Sowerbyella–Onniella* Community
    - Strophomenid Population
    - Orthid-Crinoid Population
- *Orthorhynchula–Ambonychia* Community
    - Linguloid Population
    - Rhynchonellid Population
    - Modiolopsid Population
- *Zygospira–Hebertella* Community
    - Spiriferid Population
    - Orthid Population

It is important to emphasize that the definition of communities and populations is quite distinct from that of the systematically segregated faunal provinces. The bryozoan, brachiopod, gastropod and bivalve faunal provinces occupied distinct geographic areas within the central Appalachians and were strictly defined by the presence or absence of a particular fauna, whereas the Late Ordovician communities are composed of numbers of recurrent species, one or more of which may be absent or rare at a given locality within the area occupied by the community.

The areal distribution of the three communities throughout the Upper Ordovician is shown in Figure 24. This is not a reconstruction based on the stratigraphic or sedimentological framework, but rather a plot of the collected data for each central Appalachian exposure. These data can further be viewed stratigraphically, as presented in Figure 6. It cannot be overemphasized that both geographic and stratigraphic presentations are based solely on the association and recurrence of the abundant Upper Ordovician species. Figure 6 also details the stratigraphic distribution of the seven multi-species populations. The biofacies relationships of these populations are the basis for a reconstruction of the faunal distribution along the central Appalachian Late Ordovician shelf.

Figure 25 is a reconstruction of the onshore to offshore community distribution based on stratigraphic relationships (Fig. 6), present geographic distribution (Fig. 24), autecological interpretations of the individual faunas (Figs. 20-23) and the Late Ordovician sedimentological framework of a prograding depositional regime (Fig. 12). Figures 26 and 27 are profiles taken across this reconstructed central Appalachian Late Ordovician shelf, showing the inferred distribution of the abundant faunal elements (see also Figs. 10 and 11, showing Late Ordovician depositional environments). These figures emphasize the pronounced nearshore to offshore change in abundant faunas, although there is considerable mixing and overlap of the individual species. In Figure 28 the diversity of the preserved Late Ordovician shelf fauna is contoured. The low diversity of nearshore and offshore environments, although documented in the Late Ordovician only by those animals preservable as fossils, is also characteristic of Recent environments. The Late Ordovician nearshore low count (C in Fig. 28) was probably caused by salinity, temperature and desiccation stress conditions in the lagoonal and tidal flat environments of the upper Reedsville and lower Oswego strata, and by shifting substratum along the margins of the lower Oswego bars and barriers. The offshore low diversity (C′ in Fig. 28) found only in the north, represents predominantly a trilobite fauna not examined in detail, and is common in the lower Reedsville gray-black muds; it appears to reflect, by analogy with

LATE ORDOVICIAN FAUNAL ASSOCIATIONS

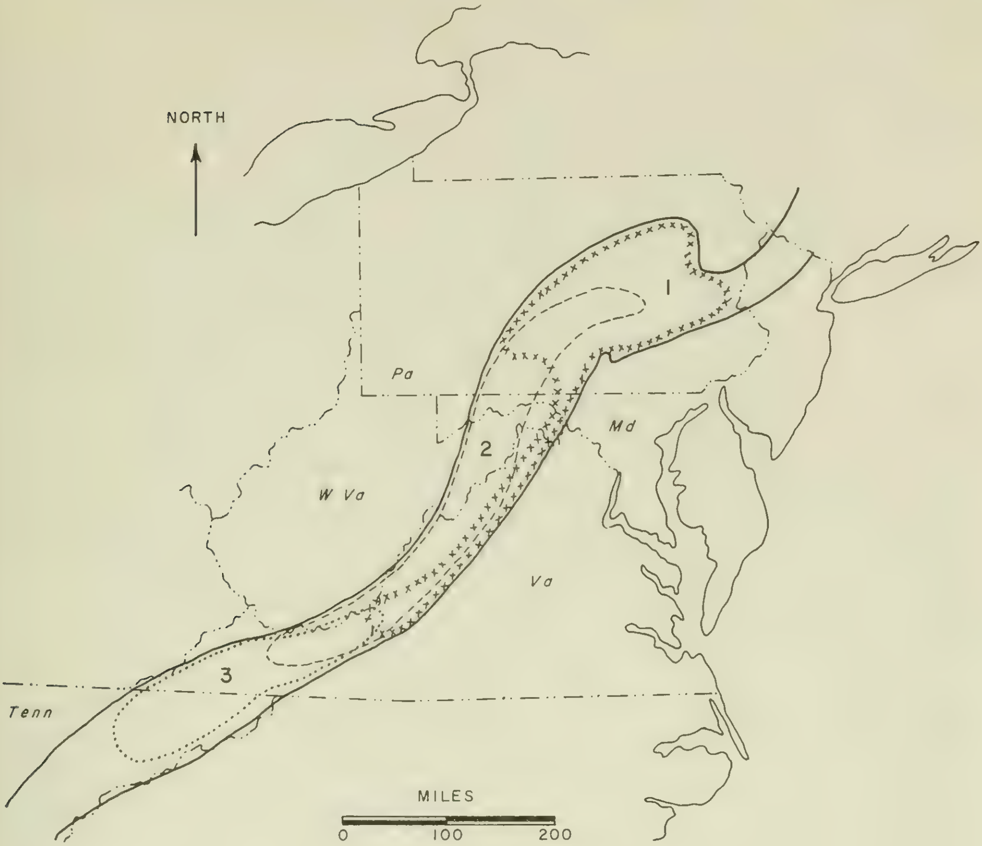
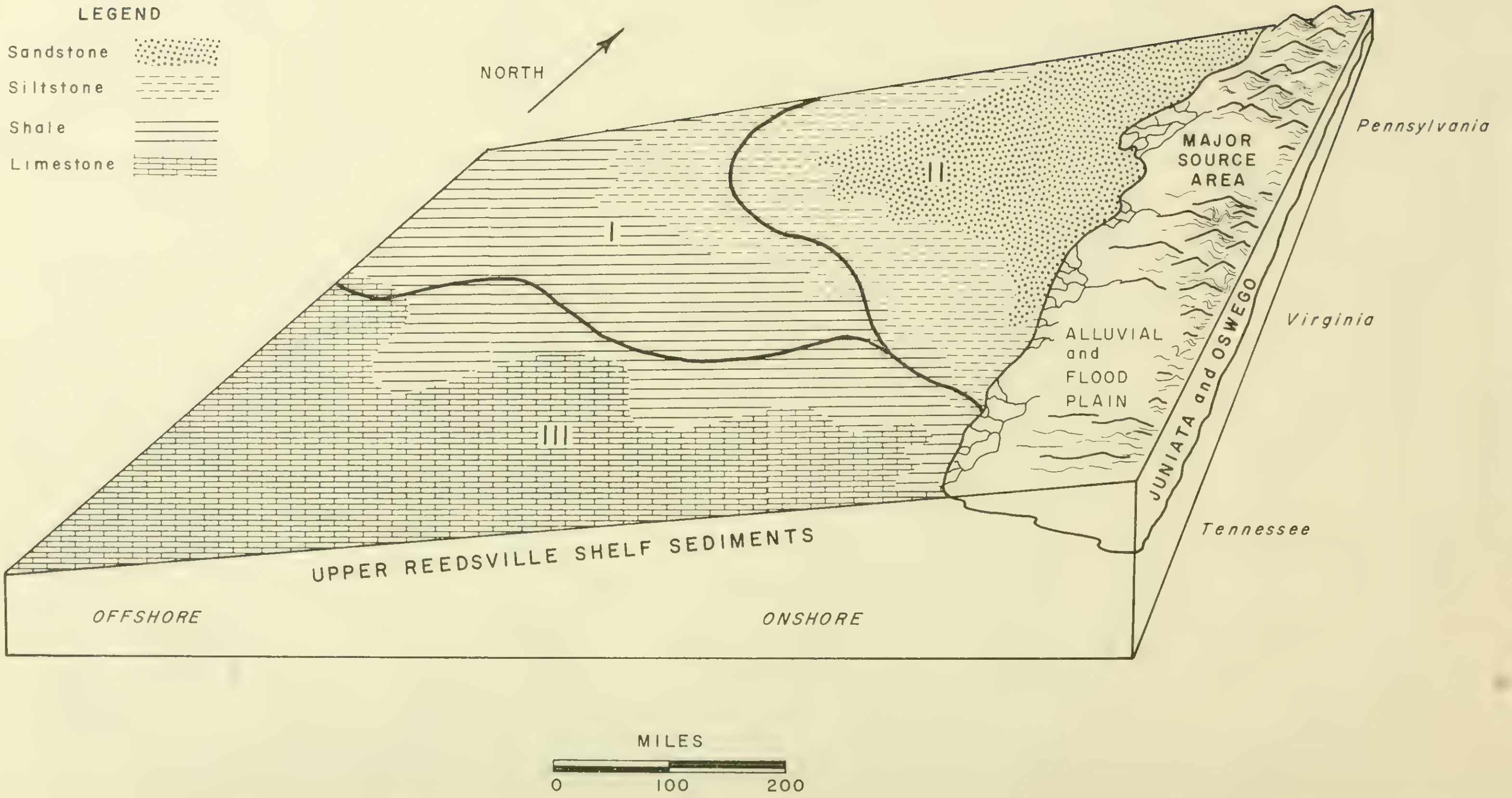


FIG. 24. Distribution of Late Ordovician faunal associations (Communities) in the central Appalachians. The data from Figures 13, 14, 16 and 17 are combined to form this distributional pattern (see Table 9 for species composition). Figure 6 outlines the stratigraphic relationships of the faunal association overlaps.

The communities are:
1. *Sowerbyella–Onniella* Community
2. *Orthorhynchula–Ambonychia* Community
3. *Zygospira–Hebertella* Community

Recent environments, an area of low primary benthonic productivity and poor circulation with a low level of oxidation, which is expressed in the texture and coloration of the sediments. The areas of high fossil diversities (A and A′ in Fig. 28) indicate regions of high primary productivity, normal marine bottom salinities, hence adequate circulation, and suitable substratum attachment sites for the numerous benthic, epifaunal suspension feeding trepostomatous bryozoans (A′) and the articulate brachiopods (A and A′). Also included in the high diversity in the north (A) are high numbers of infaunal deposit-feeding protobranch bivalve molluscs, which emphasize not only an adequate food supply for the suspension feeders but sufficient organic detritus to support a major infaunal element.

ENVIRONMENTAL SETTING—LATE ORDOVICIAN COMMUNITIES


LEGEND
Sandstone
Siltstone
Shale
Limestone
NORTH
I
II
III
MAJOR SOURCE AREA
ALLUVIAL and FLOOD PLAIN
JUNIATA and OSWEGO
Pennsylvania
Virginia
Tennessee
UPPER REEDSVILLE SHELF SEDIMENTS
OFFSHORE
ONSHORE
MILES
0
100
200

SOWERBYELLA–ONNIELLA COMMUNITY

The fauna of the *Sowerbyella–Onniella* Community occupies an area extending from eastern and central Pennsylvania to north-central Virginia (see also Bretsky et al., 1969). The environmental setting was presumably outer sublittoral, slightly off and to the north of the Late Ordovician deltaic complex (see Figs. 25 and 26). The predominant substratum type was a silty mud and silt; the fauna appears to have been totally normal marine. Of the two populations which compose the *Sowerbyella–Onniella* Community, the Orthid–Crinoid Population is found most in silty muds, is dominated by *Onniella multisecta* and crinoids, and has an overall high faunal diversity (Table 10). This population grades seaward into a sparse trilobite fauna which is found in a dark lower Reedsville mud. Species in the Orthid–Crinoid Population grade shoreward into the Strophomenid Population. This latter population is completely dominated by the strophomenid brachiopods *Sowerbyella* (*Sowerbyella*) *sericea* and *Rafinesquina* "*alternata*". This Strophomenid Population is, however, only locally abundant in a medium to coarse silt and has a considerably lower faunal diversity than the Orthid–Crinoid Population (Table 10). The strophomenid brachiopods are gradually outnumbered by pleurotomariid gastropods in northern Virginia. Although more characteristic of coarser sediment than the Orthid–Crinoid Population, the Strophomenid population ends abruptly shoreward, showing little gradation into the faunas of the *Orthorhynchula–Ambonychia* Community, which occupies a similar type of bottom but closer to shore.

The faunas of both these populations tend to be patchily distributed within the *Sowerbyella–Onniella* Community and individuals of a species are often gregarious. The common epifaunal suspension feeders (articulate brachiopods) and epifaunal and infaunal detritus feeders (pleurotomariids and nuculoids) are rarely found mixed together, but recur throughout many local stratigraphic sections. The community is rather abruptly terminated in east-central Virginia, where it ends in a sequence of well-laminated silts and muds, totally unfossiliferous and seemingly undisturbed by biogenic activity. This environmental situation finds a Recent analogue in the deeper-water basin and sill environment described off the coast of southern California by Emery and Hulsemann (1962). Bayer (1967) outlined what appears to be an isocommunity or parallel community from the Mid-Continent Upper Ordovician rocks. Bayer's *Thaerodonta* (= *Eoplectodonta*)–*Onniella* Community has as its major faunal components the *Sowerbyella*-like *Thaerodonta*, *Onniella*, *Ctenodonta similis* (a nuculoid, probably *Palaeoconcha*) and *Isotelus*.

FIG. 25. Environmental reconstruction of the Late Ordovician Communities in the central Appalachians based on stratigraphic, sedimentological and faunal evidence (see Fig. 24 which outlines the distribution of Upper Ordovician faunal associations directly from locality data with no environmental interpretations). The generalized distribution of the communities is portrayed at some time during the deposition of the Oswego barrier-lagoonal deposits along the northeastern shoreline. The communities are:

I. *Sowerbyella–Onniella* Community
II. *Orthorhynchula–Ambonychia* Community
III. *Zygospira–Hebertella* Community

The scale refers to distance along shoreline; onshore to offshore exaggeration is approximately ×4.

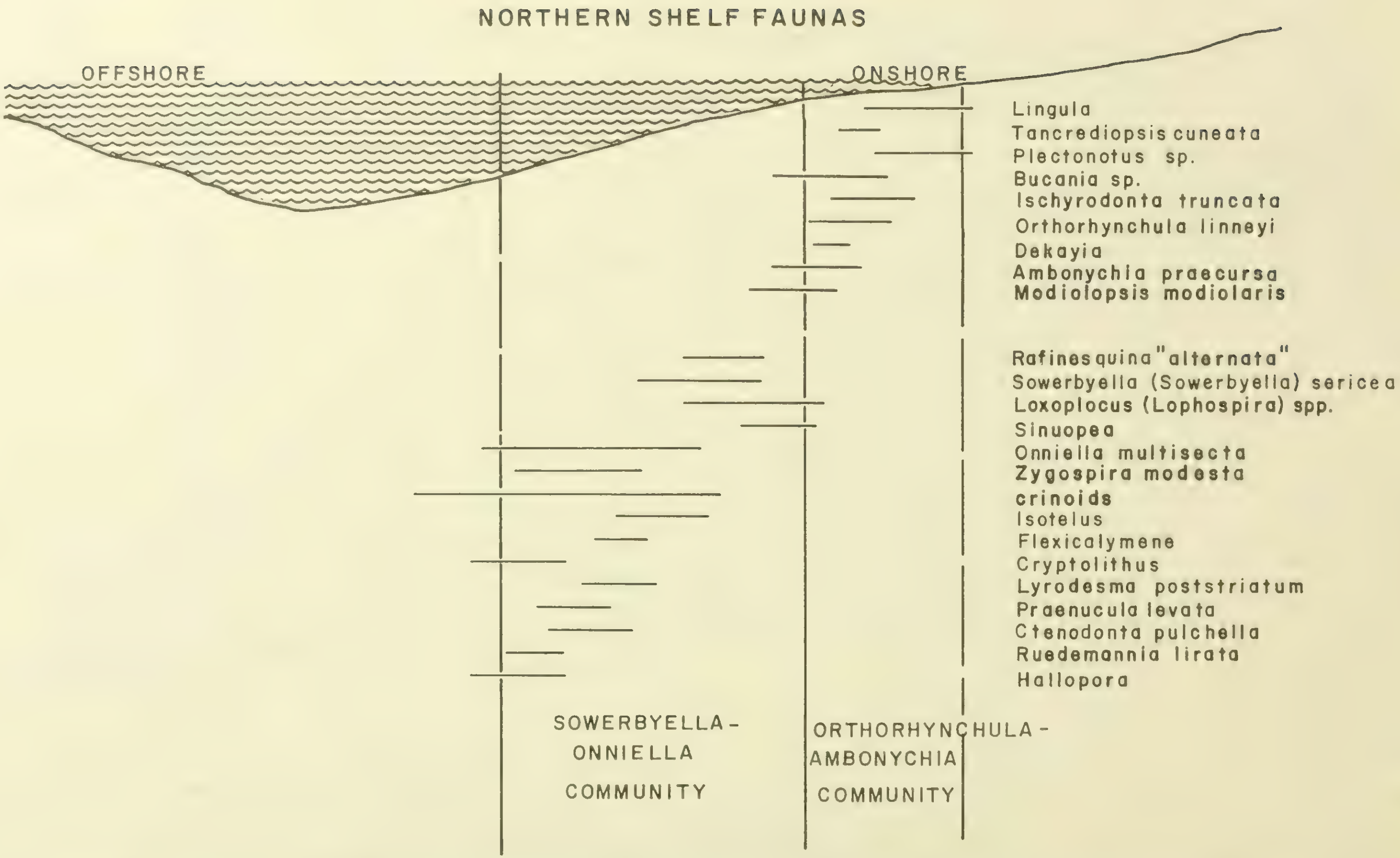

NORTHERN SHELF FAUNAS
OFFSHORE
ONSHORE
Lingula
Tancrediopsis cuneata
Plectonotus sp.
Bucania sp.
Ischyrodonta truncata
Orthorhynchula linneyi
Dekayia
Ambonychia praecursa
Modiolopsis modiolaris
Rafinesquina "alternata"
Sowerbyella (Sowerbyella) sericea
Loxoplocus (Lophospira) spp.
Sinuopea
Onniella multisecta
Zygospira modesta
crinoids
Isotelus
Flexicalymene
Cryptolithus
Lyrodesma poststriatum
Praenucula levata
Ctenodonta pulchella
Ruedemannia lirata
Hallopora
SOWERBYELLA-ONNIELLA COMMUNITY
ORTHORHYNCHULA-AMBONYCHIA COMMUNITY

FIG. 26. The inferred distribution of the abundant faunas in the *Orthorhynchula–Ambonychia* and *Sowerbyella–Onniella* Communities. Refer to Figures 10, 11 and 12 for a more complete reconstruction of the sedimentological setting (cf. Fig. 27, southern shelf faunas).

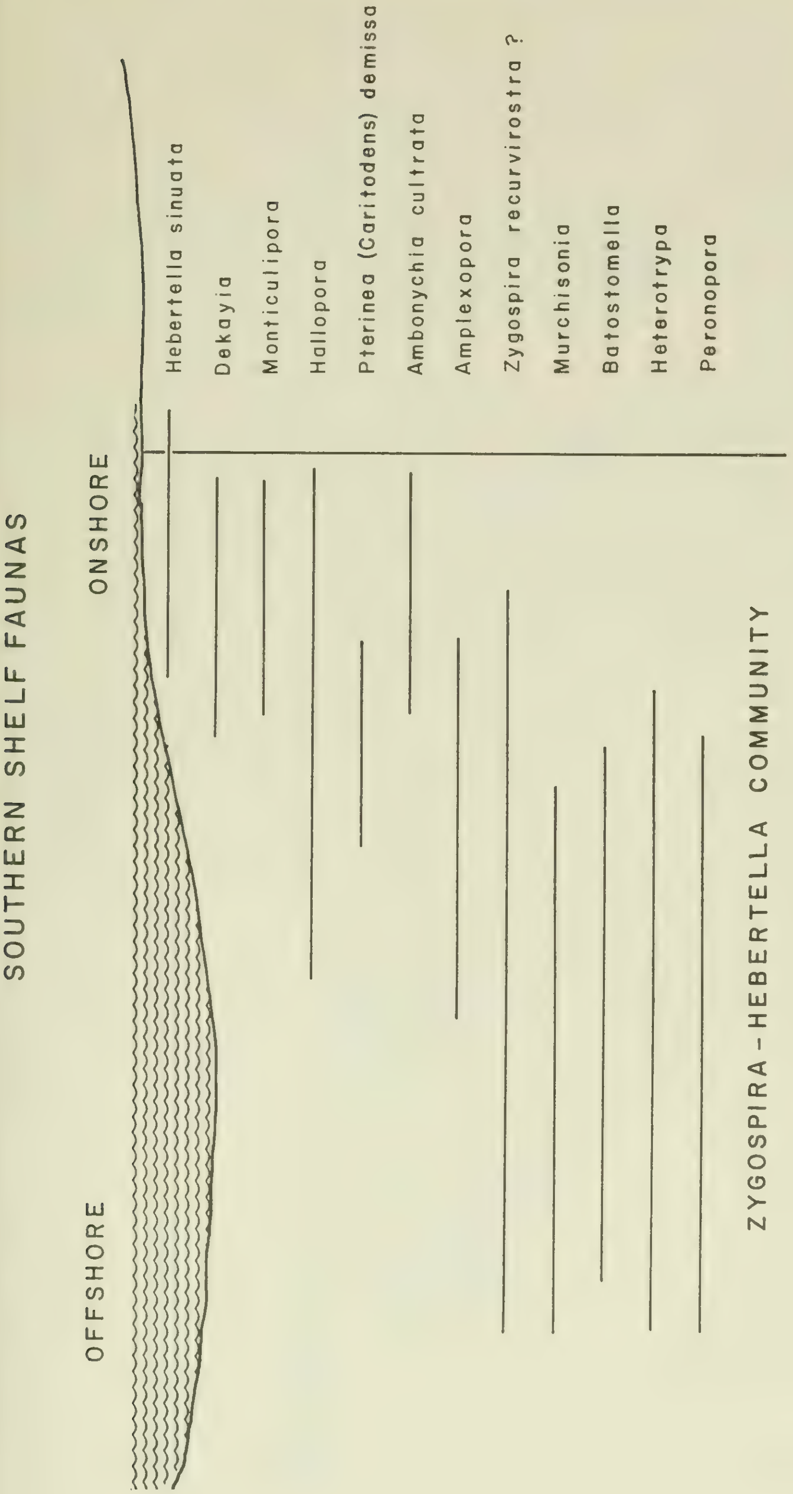
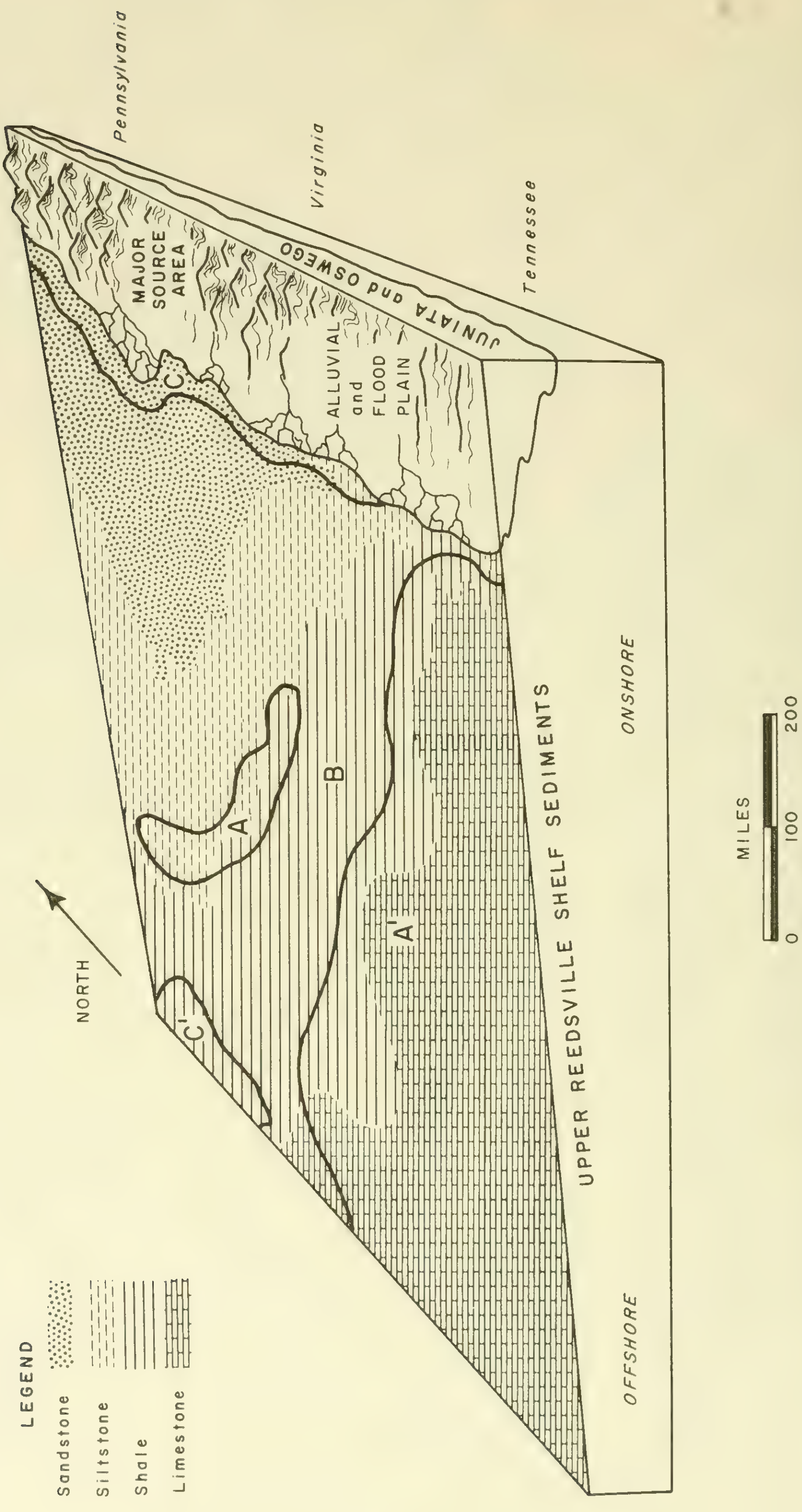


FIG. 27. The inferred distribution of the abundant faunas in the *Zygospira–Hebertella* Community. Refer to Figures 10, 11 and 12 for a more complete reconstruction of the sedimentological setting (cf. Fig. 26. northern shelf faunas).

LATE ORDOVICIAN DIVERSITY


Pennsylvania
Virginia
Tennessee
JUNIATA and OSWEGO
MAJOR SOURCE AREA
ALLUVIAL and FLOOD PLAIN
C
A
B
A'
C'
NORTH
UPPER REEDSVILLE SHELF SEDIMENTS
ONSHORE
OFFSHORE
MILES
0
100
200
LEGEND
Sandstone
Siltstone
Shale
Limestone

The Orthid–Crinoid Population may be compared to the Recent *Yoldia hyperborea* Community of Sparck (1937). This community is common in subarctic waters of 10 to 70 meters depth, and its fauna is dominated by a variety of infaunal, detritus feeding protobranchs (*Yoldia*, *Nucula* and *Leda*) in a muddy substratum. The Late Ordovician Orthid–Crinoid Population in north-central Pennsylvania consists, in part, of an abundant but patchy distribution of the infaunal photobranch genera *Ctenodonta*?, *Praenucula* and *Palaeconcha*, also in a muddy substratum. The analogy is made to emphasize only an apparent similarity in the feeding habits of the abundant bivalve molluscs in Recent and Late Ordovician muds. Any extrapolation of depth and temperature conditions is very speculative.

ORTHORHYNCHULA–AMBONYCHIA COMMUNITY

The fauna of the *Orthorhynchula–Ambonychia* Community extends from south-central Pennsylvania to south-central Virginia. The environmental setting appears to have been predominantly inner sublittoral and intertidal. The sediments preserve a record of nearshore environments, including barriers, beaches and lagoons, and these particular faunas appear to have thrived only in this sedimentological regime (Figs. 25 and 26). The substratum was highly variable, from a muddy silt and silty sand to a coarse, well-sorted sand. It appears that members of the community were able to tolerate periods of variable salinity.

The nearest-shore fauna, the Linguloid Population, is dominated by large numbers of very few species (Table 10). This population is in some way related to the proximity of an upper Reedsville—lower Oswego shallow marine-barrier-lagoonal environment (see Fig. 8) that developed immediately south of the Late Ordovician deltaic complex in central Pennsylvania (Fig. 25). It is possible that the southward transport of sands by longshore currents from this deltaic complex permitted the development of the barriers. Directly seaward of the barriers in the upper Reedsville are found organically rich muddy silts and sands, highly reworked biogenically, and inhabited by a few eurytypic species able to tolerate the variable stress conditions such as changes in salinity and current reworking of the bottom sediment. Conditions of variable intensity of current reworking are manifested by occasional concentrated patches of phosphate grains, which accumulated in shallows during periods of low sedimentation, limited circulation and high productivity. In direct contrast are the interbedded,

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FIG. 28. Reconstruction of Late Ordovician generic diversity in the central Appalachians based on apparent diversity as shown only by those animals preservable as fossils. It is important to note, however, that the onshore to offshore low fossil diversities are characteristic of Recent shelf environments. The stratigraphic-sedimentological framework is the one used in Figures 20-23 and Figure 25 (see esp. Fig. 25 for generalized environmental distribution of Late Ordovician communities).

Diversity	Genera
A & A′ — High	>15
B — Moderate	6-15
C & C′ — Low	1-5

The scale refers to distance along the shore; onshore to offshore exaggeration is approximately ×4.

TABLE 10. Central Appalachian Late Ordovician Communities and Populations.

1. *Sowerbyella–Onniella* Community	
STROPHOMENID POPULATION	
Brachiopoda:	(strophomenids) *Sowerbyella* (*Sowerbyella*) *sericea* *Rafinesquina "alternata"*
Gastropoda:	(pleurotomariids) *Loxoplocus* (*Lophospira*) *abbreviata* *L.* (*L.*) *perangulata* *L.* (*L.*) *ventricosta* *Sinuopea?*
ORTHID-CRINOID POPULATION	
Bryozoa:	(trepostome) *Hallopora*
Brachiopoda:	(orthid) *Onniella multisecta* (spiriferid) *Zygospira modesta* (strophomenid) *Sowerbyella* (*Sowerbyella*) *sericea*
Gastropoda:	(pleurotomariid) *Ruedemannia? lirata*
Bivalvia:	(nuculoids) *Ctenodonta? pulchella* *Praenucula levata* *Lyrodesma poststriatum* (ambonychiid) *Ambonychia radiata*
Trilobita:	*Isotelus* *Flexicalymene* *Cryptolithus*
Crinoidea:	crinoid columnals — unidentifiable

2. *Orthorhynchula–Ambonychia* Community	
LINGULOID POPULATION	
Brachiopoda:	(linguloid) *Lingula?* (bellerophontids)
Gastropoda:	*Plectonotus?* *Bucania?*
Bivalvia:	(nuculoid) *Tancrediopsis cuneata* (modiomorphid or trigonoid) *Ischyrodonta truncata*
RHYNCHONELLID POPULATION	
Bryozoa:	(trepostome) *Dekayia*
Brachiopoda:	(rhynchonellid) *Orthorhynchula linneyi*
Bivalvia:	(modiomorphid) *Modiolopsis modiolaris* (ambonychiid) *Ambonychia praecursa*
MODIOLOPSID POPULATION	
Bivalvia:	(modiomorphid) *Modiolopsis modiolaris* (ambonychiids) *Ambonychia praecursa* *Ambonychia cultrata*

3. *Zygospira–Hebertella* Community	
SPIRIFERID POPULATION	
Bryozoa:	(trepostomes) *Batostomella* *Heterotrypa* *Peronopora?* *Monticulipora* *Hallopora* *Amplexopora*
Brachiopoda:	(spiriferid) *Zygospira recurvirostra*
Gastropoda:	(murchisoniid) *Murchisonia?*
Bivalvia:	(pterioid) *Pterinea* (*Caritodens*) *demissa* (ambonychiids) *Ambonychia cultrata* *Ambonychia radiata?* (modiomorphid) *Modiolopsis modiolaris*
ORTHID POPULATION	
Bryozoa:	(trepostomes) *Hallopora* *Dekayia* *Monticulipora*
Brachiopoda:	(orthid) *Hebertella sinuata* (rhynchonellid) *Orthorhynchula linneyi* (strophomenid) *Rafinesquina "alternata"*

TABLE 11. A summary of the central Appalachian Upper Ordovician Communities. Included is a brief outline of possible Recent analogues which must be viewed, however, as only very general approximations. The material incorporated within this table is reviewed in the text.

Communities	*Sowerbyella–Onniella*	*Orthorhynchula–Ambonychia*	*Zygospira–Hebertella*
Geographic location	eastern and central Pa. to north-central Va.	south-central Pa. to south-central Va.	southwestern Va. and northern Tenn.
Major substratum type	silts — silty muds	sands — muddy silts	silty muds — muds — lime muds
Inferred environmental setting	outer sublittoral; seaward of deltaic complex.	shallow inner sublittoral and intertidal, including barrier–beach–lagoonal environments; integrally associated with deltaic complex sedimentation.	inner and outer sublittoral on a broad, gently sloping shelf; south of main deltaic complex and influx of terrigenous clastics; possible tidal flat environments.
Possible recent analogues to Late Ordovician populations	Orthid–Crinoid Population: *Yoldia hyperborea* Community, muds — 10 to 70 meters — subarctic — abundant *Yoldia*, *Nucula*, *Leda* (Sparck, 1937).	Linguloid Population: 1. Enclosed lagoon — North Gulf (Parker, 1960). 2. *Nucula proxima-Nepthys incisa* Community, muds, silty muds — L. I. Sound, Buzzards Bay (Sanders, 1953, 1956, 1960). 3. *Syndosmya* Communities, shallow mud bottoms, sheltered and estuarine Danish waters (Thorson, 1957).	Spiriferid Population: *Turritella* or *Cerithium* Communities, soft mud bottoms, shallow to moderate inner sublittoral depths (Thorson, 1957).

well-sorted, cross-bedded sands of the bars and barriers. Figure 29 reconstructs a very general environmental setting of the Linguloid Population, showing both the dominance of the epifaunal and infaunal detritus feeders and the probable primary food source in the lagoonal and off-beach algal stands. The beach and tidal flat environments of the lower Oswego are characterized by only a few elongate, slender, vertical worm tubes and a very few linguloids. Seaward, however, the Linguloid Population grades rapidly into the Rhynchonellid and Modiolopsid Populations. The former, dominated by *Orthorhynchula linneyi* and *Ischyrodonta truncata*, is located seaward of the bars and barriers where there is a sandy bottom, whereas the Modiolopsid Population, *Ambonychia praecursa* and *Modiolopsis modiolaris*, seems to have preferred a muddier substratum. Gradations are common between these two latter populations, but where the silts become extremely muddy only the Modiolopsid Population, and *Modiolopsis modiolaris* in particular, is numerous. The faunas of both Rhynchonellid and the Modiolopsid Populations are composed of epifaunal suspension feeders, of moderate diversity, occasionally patchy in distribution, resembling Recent shallow mussel-dominated habitats. The sediment is, however, often thoroughly reworked; a major infaunal element may thus have been locally present. Whereas the Linguloid Population ends abruptly in central Virginia (see Fig. 6) with little evidence of mixing with the *Zygospira–Hebertella* Community, some species of the Rhynchonellid and Modiolopsid Populations grade over a fairly broad area with the dominant southern faunas. In the north there is only a very limited seaward mixing with the faunas of the *Sowerbyella–Onniella* Community.

A review of the Recent marine literature points up three possible modern analogues to the Linguloid Population: the enclosed lagoonal assemblage along the northern coast of the Gulf of Mexico (Parker, 1960, p. 310); the *Nucula proxima–Nepthys incisa* Community in the muds of Buzzards Bay, Massachusetts, and Long Island Sound (Sanders, 1956, 1958, 1960); and the *Syndosmya* Communities in the sheltered mud bottoms and estuaries along the coast of Denmark (Thorson, 1957, p. 510). In diversity, numbers and kinds of species, bathymetric position and substratum type, these Recent communities are quite comparable to the Late Ordovician environmental setting of the Linguloid Population.

ZYGOSPIRA–HEBERTELLA COMMUNITY

The fauna of the *Zygospira–Hebertella* Community extends over much of southwestern Virginia and northern Tennessee. The environmental setting appears to have included both inner and outer sublittoral regimes, with possibly an occasional lagoonal or tidal flat occurrence. The broad, gently sloping shelf that seems to have existed in the south-central Appalachians during the Late Ordovician allowed for the development of a virtual shallow epicontinental sea. This area was well south of the major terrigenous influx (Figs. 25 and 27). The predominant substratum type was a silty mud, mud and lime mud. The environment appears to have been normal marine in character with the exception of a few places where brackish water would have existed on low, gently sloping tidal flats.

In the central Appalachians the *Zygospira–Hebertella* Community is the closest approximation to a typical, highly diversified Mid-Continental shallow sea fauna.

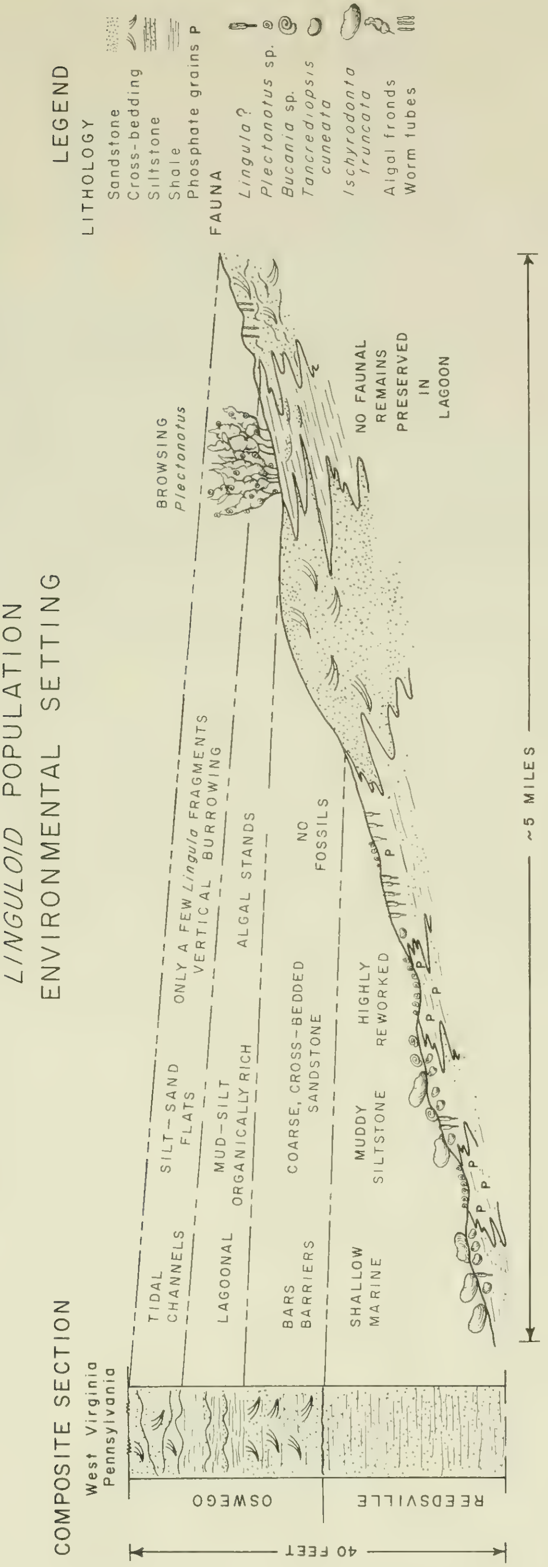
LINGULOID POPULATION
ENVIRONMENTAL SETTING
COMPOSITE SECTION
West Virginia
Pennsylvania
OSWEGO
REEDSVILLE
40 FEET
TIDAL CHANNELS
LAGOONAL
BARS BARRIERS
SHALLOW MARINE
SILT-SAND FLATS
MUD-SILT ORGANICALLY RICH
COARSE, CROSS-BEDDED SANDSTONE
MUDDY SILTSTONE
ONLY A FEW *Lingula* FRAGMENTS
VERTICAL BURROWING
ALGAL STANDS
NO FOSSILS
HIGHLY REWORKED
~5 MILES
BROWSING *Plectonotus*
NO FAUNAL REMAINS PRESERVED IN LAGOON
P
LEGEND
LITHOLOGY
Sandstone
Cross-bedding
Siltstone
Shale
Phosphate grains P
FAUNA
Lingula ?
Plectonotus sp.
Bucania sp.
Tancrediopsis cuneata
Ischyrodonta truncata
Algal fronds
Worm tubes

FIGURE 29.

The community is dominated by epifaunal suspension feeders. The species are generally very widespread and the individual populations tend to be much less patchy than those in the north-central Appalachians. Although both Spiriferid and Orthid Populations contain numerous trepostomatous bryozoans, *Zygospira recurvirostra* is consistently characteristic of the muds and lime muds, along with a variety of epifaunal, suspension feeding ambonychiid and pterioid bivalves and the possibly epifaunal murchisoniid gastropods. The Orthid Population is characterized by numerous *Hebertella sinuata* and the trepostomes *Monticulipora* and *Dekayia* in silty muds and muddy silts. The Spiriferid and Orthid Populations intergrade over the entire area covered by the *Zygospira–Hebertella* Community, and both also exhibit considerable mixing with the Rynchonellid and Modiolopsid Populations of the *Orthorhynchula–Ambonychia* Community to the north and northeast. There is, however, only limited mixing with the deeper-water *Sowerbyella–Onniella* Community to the north.

There is one possible Recent analogue to the Spiriferid Population, the *Turritella* or *Cerithium* Communities that occupy soft mud bottoms at shallow to moderate inner sublittoral depths (Thorson, 1957, p. 514). The analogy is again only a rough approximation of the probable Late Ordovician environmental settings. Table 11 is a brief survey of the environmental settings and probable Recent analogues of the central Appalachian Late Ordovician communities.

CONCLUSIONS

This study has shown that the Upper Ordovician rocks in the central Appalachians enclose a shallow marine fauna that exhibits not only a distinctive onshore to offshore distributional pattern but also a longshore one. The combined zoogeographic and autecological study also has pointed out that the nearshore environments are commonly dominated by bellerophontid gastropods, nuculoid and modiomorphid bivalve molluscs, and linguloid and rhynchonellid brachiopods, whereas the offshore regimes are composed predominantly of orthid, strophomenid and spiriferid brachiopods, crinoids and trepostomatous bryozoans. This general distributional pattern is modified significantly by the position of the major source area in central Pennsylvania as the characteristically offshore brachiopods and bryozoans come to occupy more nearshore environments in southwestern Virginia and northern Tennessee farther away from this major deltaic complex. The effect of this deltaic complex acting as a barrier to the migration and dispersal of the Late Ordovician benthic marine invertebrates has yet to be explored in detail since this study was confined exclusively to those marine environments immediately off and to the south of the complex.

The recognition of these three Late Ordovician benthic invertebrate communities furthermore has emphasized the likelihood of mapping parallel benthic communities for any segment of the geologic past, and will not only permit more detailed explanations of the evolutionary development of selected taxonomic groups, but also presents the issue of community stability and evolution over extended periods of geologic time. Many problems of the evolution of stable community structures — what kinds of benthic communities are stable, where they are most stable and how long they remained stable — remain virtually untouched. Additional studies of Late Ordovician fossiliferous rocks in eastern and central North America should provide the data needed to elaborate the development of benthic community structures on these Late Ordovician shelf environments. Only a few other Paleozoic studies, however, have emphasized the community approach in studying the history of life. The most noteworthy contributions are Copper's (1966) study of Devonian atrypid brachiopods, which is primarily autecological; and the synecological studies of Elias (1937), Johnson (1962), Zangerl and Richardson (1963), Laporte (1967), Stevens (1966) and Sutton et al. (1966). There is a great need for further detailed paleoecological investigations throughout the entire Paleozoic record in order to attempt to trace well-defined fossil communities throughout this extended period of geologic time.

Although the structure of marine benthic communities is generally thought to be relatively uncomplicated, and the basic food-web pattern (producers, consumers, decomposers and transformers) was probably established by the early Paleozoic, the prospects for studying community evolution in the Paleozoic are especially promising. This is the time of initial phylogenetic radiation of many invertebrate groups. The length of time a community maintains a constant faunal composition would seem to provide a key to the evolution of a stable community structure. By tracing the evolution of marine invertebrate community structures throughout a long period of geologic time, we can begin to document variable rates of change in the faunal composition of the community and thus recognize particular benthic environmental settings where community stability or instability exists.

A synthesis of detailed Paleozoic community faunal compositions should point out major changes in the faunal composition on benthic communities at particular times and in specific places on the marine shelf. Periods of major reorganization of shelf invertebrate faunas are well known and have been the subject of numerous papers especially concerned with the causal factors in this change in faunal composition. To date one of the more serious flaws in any discussion of the paleoecology and evolution of benthic invertebrates is that the invertebrate taxa have been considered as almost exclusively separate entities or as parts of only a very general marine realm. With increased knowledge of these ancient communities, species and higher categories may be viewed as part of an integrated community structure subject to a variety of biotic and physio-chemical factors whose interactions determine the stability or instability of the organization of a particular community.

SYSTEMATIC PALEONTOLOGY

INTRODUCTION

In this study of the central Appalachian Upper Ordovician faunas more than 95 per cent of the total fauna belonged to three phyla: Bryozoa, Brachiopoda and Mollusca (Gastropoda and Bivalvia). Specimens of Arthropoda (Trilobita) and Echinodermata (Crinoidea) were much more scattered and rare. Since identification of the abundant specimens was critical to the outlining of the zoogeographic distribution and faunal associations, preliminary ecological data, identifications, and descriptions of the various Bryozoa, Brachiopoda, Gastropoda and Bivalvia were submitted to specialists within each field for their critical evaluation. Species-level taxonomy was normally possible within the Brachiopoda and Mollusca, given sufficiently well-preserved materials. Within the Bryozoa, however, generic identifications were thought reasonably sound, but species-level taxonomy in this group awaits a more thorough taxonomic investigation.

For the major part of this study, I examined material which I had collected from the central Appalachians. Descriptions and identifications, however, were reviewed in light of the relevant comparative literature for the Paleozoic of North America as well as some outstanding taxonomic contributions on the Lower Paleozoic faunas of Europe. I attempted to place each central Appalachian taxon into the most acceptable category. No new taxa are introduced, but my reservations concerning any particular classification are placed in the discussion of each taxon. Synonymies are included where species-level identification seemed feasible in view of the data I had accumulated. Previous descriptions from strictly systematic literature could, I believe, be somewhat more critically evaluated in light of the new ecological data, i.e., an integrated morphological and distributional approach. It cannot be overstressed that features unknown to me in any of the taxa described may be found in other collections. The following descriptions pertain only to those specimens collected by me from the Upper Ordovician rocks of the central Appalachians.

The format used in this section normally consists of Synonymy-Description-Materials-Discussion for each species, but a general discussion is substituted where species-level taxonomy was not possible. All the materials used in this study are deposited in the Peabody Museum of Yale University along with a complete card index indicating species abundance, faunal and lithologic associations for the individual taxon at each locality and/or horizon. Localities are listed by number on p. 135.

BRYOZOA

Plates 3-9

The Bryozoa constitute an important faunal element in the central Appalachian Upper Ordovician clastic facies. Although normally less abaundant than the Mollusca and Brachiopoda, Bryozoa may be co-dominant locally with spiriferid, orthid and rhynchonellid brachiopods.

A survey of the central Appalachian Ordovician literature reveals an almost complete lack of recent bryozoan taxonomic investigations, and as Boardman and Utgaard (1966, p. 1082) pointed out, there are few usable illustrations of the established Paleozoic taxa. Current taxonomic philosophies and concepts stress the re-evaluation of type materials through extensive microsectioning; much of the pre-1960 bryozoan literature lacks adequate treatment of microstructure and therefore is of limited use. Utgaard and Perry (1964) presented detailed descriptions of some Upper Ordovician trepostomatous bryozoans and included a valuable historical review of these changing taxonomic philosophies with special reference to the Cincinnatian Mid-Continent species. Recent papers of taxonomic value used in studying the Bryozoa are those of Bassler (1953), Boardman (1960), Ross (1963) and Brown (1965). Particularly useful were earlier papers by Cumings (1908) and Cumings and Galloway (1913, 1915), in which numbers of zooecial wall microstructures were examined in detail for the first time.

The current taxonomic re-evaluation by those investigators mentioned above places the definition of many Paleozoic taxa in doubt. I have undertaken only a generic-level assignment of the central Appalachian bryozoan taxa. Species-level bryozoan taxonomy would not have contributed materially to this study and probably should await complete taxonomic reviews.

PHYLUM BRYOZOA
SUBPHYLUM ECTOPROCTA
CLASS GYMNOLAEMATA
ORDER TREPOSTOMATA
SUBORDER AMALGAMATA
FAMILY MONTICULIPORIDAE

GENUS *MONTICULIPORA*

Plate 3, figures 1-3

Identification of the genus *Monticulipora* is based on the analysis of 12 microsections of specimens from localities in southwestern Virginia. The zoaria are characteristically ramose and frondescent; the median diameter of the 12 sectioned specimens is 11 mm. Zooecial walls are thin in the endozone but finely laminated zooecial linings are present in the exozone. Planar and cystose diaphragms are abundant throughout the entire zooecium. Mesopores are common and clustered on monticules; there are few acanthopores and these occur only at zooecial corners.

Assignment of these specimens to the genus *Monticulipora* is substantiated by the recent generic redescription by Boardman and Utgaard (1966, p. 1093). Excellent plates and descriptions of certain Cincinnatian species of *Monticulipora* are also presented by Utgaard and Perry (1964, p. 42). I tried to avoid possible misidentification of these specimens with the very similar genera *Prasopora* or *Prasoporina* by using an extensive Paleozoic trepostome catalogue made available to me by Dr. Richard Boardman of the U. S. National Museum.

The genus *Monticulipora* is abundant (see Table 3 for numbers; relative density index equal to or greater than 3) only at localities 141 and 142 in southwestern Virginia, although it is present at a number of nearby localities (loc. 132, 128, 125; possibly 126 and 140; see Fig. 1). Where *Monticulipora* is abundant, the most commonly associated faunal elements are a smaller ramose *Dekayia, Zygospira recurvirostra, Ambonychia cultrata, Pterinea* (*Caritodens*) *demissa*, and *Modiolopsis modiolaris,* all part of the Spiriferid Population of the *Zygospira–Hebertella* Community. *Monticulipora* is geographically confined to southwestern Virginia and northern Tennessee; its distribution is much like that of *Batostomella* and *Amplexopora,* i.e., bryozoan faunal province III (see Fig. 13). The associated faunal elements, including *Dekayia,* are more widely distributed geographically than is *Monticulipora.*

Family HETEROTRYPIDAE

Genus *DEKAYIA*

Plate 3, figure 4; plate 4, figures 1-6; plate 5, figures 1-4

Identification of the genus *Dekayia* is based on the analysis of 41 microsections of specimens from localities in West Virginia, Virginia, and Tennessee. The zoaria are commonly ramose and have a median diameter of 9 mm. Only a few encrusting forms have been identified. Zooecial walls are characteristically thin and crenulated in the endozone, but there are distally curved, finely laminated zooecial linings in the exozone. There are a few thin, simple diaphragms in each zooecium; they are irregularly spaced in the exozone. Mesopores are rare, but acanthopores are common and are usually exozonal, oblique to the axis of the zooecia and occur at the zooecial corners.

The genera *Dekayia* and *Dekayella* were cited by various investigators as occurring in the central Appalachian Upper Ordovician clastic facies, but their figures and descriptions, for the most part, depended on hand specimens and are now of little use. It was not until Boardman and Utgaard (1966, p. 1103) emended the definitions of *Dekayia* and *Dekayella* that I was able to assign these Upper Ordovician specimens to the genus *Dekayia. Dekayella* is considered by them to be a junior subjective synonym of *Heterotrypa.*

Dekayia is one of the most widespread Bryozoa in the Upper Ordovician clastic facies (bryozoan faunal provinces II and III, see Fig. 13); only *Hallopora* is more widely dispersed. *Dekayia* is numerous in three distinctive faunal associations, the Spiriferid and Orthid Populations of the *Zygospira–Hebertella* Community and the Rhynchonellid Population of the *Orthorhynchula–Ambonychia* Community. Table 12 outlines these associations.

West Virginia locality 203 exhibits a particularly well-exposed section where there is a change in the external morphology of *Dekayia* specimens accompanying a change in the silt-mud ratio. Figure 30 depicts about 40 feet of this upper Reedsville section at locality 203 (North Fork Mountain, West Virginia). At least two samples (A-6301, A-6302) contain abundant fine, stem-like fragments in a silty mudstone. Fifteen to

TABLE 12. The associated faunal elements of *Dekayia* in northern Tennessee, southwestern Virginia and eastern West Virginia.

	Cumberland Mt., Va. Big Ridge and Wallen Ridge, Tenn.	Powell Mt., Va.	East River Mt., Peters Mt., Va. North Fork Mt., Va. and W. Va.
Locality numbers	128,132,137	141	186,190,202,203
Associated faunal elements	*Hallopora* *Hebertella sinuata* *Zygospira recurvirostra* *Murchisonia?*	*Monticulipora* *Zygospira recurvirostra* *Ambonychia cultrata* *Modiolopsis modiolaris* *Pterinea (Caritodens) demissa*	*Orthorhynchula linneyi* *Modiolopsis modiolaris* *Ambonychia praecursa*
Population	Orthid	Spiriferid	Rhynchonellid
Substratum	mud and silty mud	silty mud	muddy silt and silt

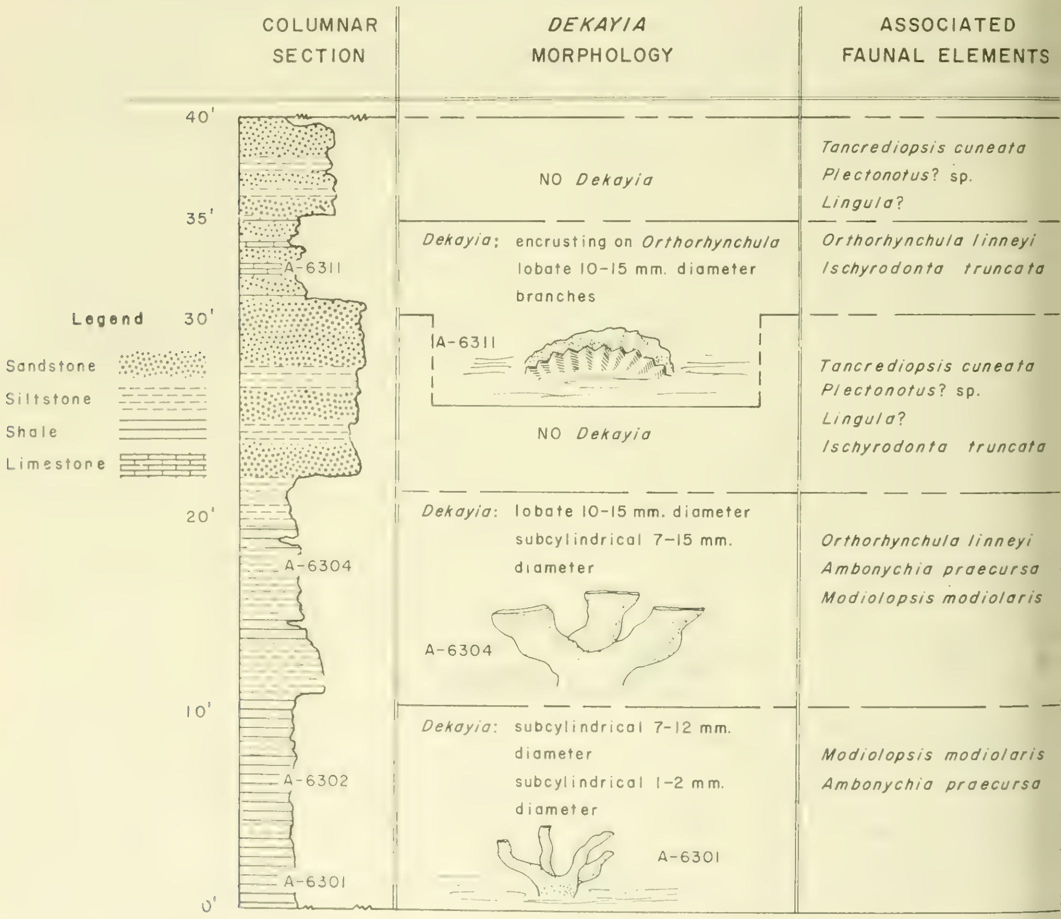
COLUMNAR SECTION
DEKAYIA MORPHOLOGY
ASSOCIATED FAUNAL ELEMENTS
40'
35'
30'
20'
10'
0'
Legend
Sandstone
Siltstone
Shale
Limestone
A-6311
A-6304
A-6302
A-6301
NO *Dekayia*
Tancrediopsis cuneata
Plectonotus? sp.
Lingula?
Dekayia: encrusting on *Orthorhynchula* lobate 10-15 mm. diameter branches
Orthorhynchula linneyi
Ischyrodonta truncata
A-6311
NO *Dekayia*
Tancrediopsis cuneata
Plectonotus? sp.
Lingula?
Ischyrodonta truncata
Dekayia: lobate 10-15 mm. diameter subcylindrical 7-15 mm. diameter
Orthorhynchula linneyi
Ambonychia praecursa
Modiolopsis modiolaris
A-6304
Dekayia: subcylindrical 7-12 mm. diameter subcylindrical 1-2 mm. diameter
Modiolopsis modiolaris
Ambonychia praecursa
A-6301

FIG. 30. Variability in external morphology of the trepostome genus *Dekayia* at locality 203 North Fork Mountain, West Virginia. "A-numbers" refer to the Peabody Museum catalogued collection.

twenty feet above the bed containing these two samples, sample A-6304 contains abundant larger cylindrical branches in addition to a few massive lobate forms in a muddy siltstone. The final appearance of numerous *Dekayia* specimens is in sample A-6311, where massive lobate and encrusting forms predominate in a shelly siltstone. The encrusting *Dekayia* are usually found on the disarticulated valves of the large rhynchonellid brachiopod *O. linneyi*. *Dekayia* is absent where the sands are fairly well sorted and there is sedimentological evidence of considerable substratum mobility, such as channeling and intraformational conglomerates.

These three distinct morphological types of Bryozoa in the Upper Ordovician are similar to modern (or Recent) bryozoan shapes and may serve as indicators of environmental setting. The nature of the substratum and the intensity of the water movement appear to be the main controlling factors in bryozoan morphology off the present Rhone delta (Lagaaij and Gautier, 1965). In the Upper Ordovician, the finer subcylindrical forms are more common in the muddier sediments; the stout lobate and encrusting habits predominate where there is a higher percentage of sand and silt (Fig. 30). All were presumably firmly attached to the substratum. Where *Dekayia* is abundant, the rates of deposition were apparently low to moderate, but turbulence may have been at a maximum higher in the section where the substratum consisted of sand and rhynchonellid brachiopod shells. All of these morphological habits are common in the Recent sublittoral, but the encrusting form may also occur in littoral regions where there is some protection from the rigors of a very turbulent environment.

FAMILY BATOSTOMELLIDAE

GENUS *BATOSTOMELLA*

Plate 6, figures 1-3

Identification of the genus *Batostomella* is based on the analysis of 45 microsections of specimens from southwestern Virginia and northern Tennessee. The zoaria are ramose and show a median diameter of 8 mm. The zooecial walls are thick and mural lacunae are occasionally abundant. Diaphragms are thin, planar and spaced regularly throughout the zooecium. Subangular mesopores are common but there are few acanthopores.

Assignment of these common Upper Ordovician specimens to the genus *Batostomella* was aided by the use of plates and descriptions given by Utgaard and Perry (1964, p. 85) and Bassler (1953, p. G99). Dr. Richard Boardman also made available an extensive catalogue of Paleozoic trepostome genera.

Specimens of *Batostomella* are abundant at localities 125, 126 and 140 in southwestern Virginia and northern Tennessee (see Table 3, Clinch Mountain), i.e. bryozoan faunal province III (see Fig. 13). As with many other trepostomes, fragments can be found at a number of nearby localities. Specimens from locality 126 are four to five times larger in diameter than those from localities 125 and 140. These larger, ramose stems average between 12 and 15 mm in diameter and show a slight increase in the number of mesopores and an abundance of mural lacunae. Finer, more delicate branches (2 to 3 mm in diameter) occur at localities 125 and 140; the zooecial walls show few, if any, mural lacunae. Boardman (pers. comm.) emphasized the importance of mural lacunae, pointing out that they have been found previously in abundance only in species of Richmond age (upper Upper Ordovician). Thus there may be not only specific differences between the *Batostomella* specimens at locality 126 and those at localities 125 and 140, but also a slight temporal discrepancy. There is, however, no significant change in the associated faunal elements: *Hallopora, Zygospira recurvirostra* and *Modiolopsis modiolaris,* which are part of the Spiriferid Population of the *Zygospira–Hebertella* Community.

Localities 125 and 140 contain, in addition to *Batostomella,* about 20 fragments of *Heterotrypa* (Pl. 7, figs. 1-2) and a peronoporid trepostome (Pl. 6, figs. 4-6). The peronoporid appears to have been an encrusting form, rather than the more common frondose, bifoliate morphological type.

The characteristic grouping of trepostomatous Bryozoa (*Batostomella, Hallopora, Heterotrypa* and *Peronopora*?) in addition to *Zygospira recurvirostra* forms a part of the Spiriferid Population and is found only along the eastern margin (Clinch Mountain, see Fig. 7) of upper Reedsville exposures in southwestern Virginia and northern Tennessee. At locality 140, where muddy siltstones rather than calcareous mudstones begin to dominate the upper portions of the Reedsville section, numerous specimens of *Batostomella* are found about 30 to 40 feet below strata dominated by *Ambonychia cultrata, Ischyrodonta truncata, Modiolopsis modiolaris,* and some *Dekayia* and *Monticulipora,* also part of the Spiriferid Population. These latter trepostomes, commonly higher in the section, are larger ramose forms in a muddy silt, occasionally encrusting on one another, whereas *Batostomella* is confined to a calcareous mud, always finely ramose, never encrusting.

The Richmondian age of *Batostomella* and the possibility of a Richmond species of *Hallopora* in northern Tennessee (see below p. 75), in contrast to northern faunal elements that are definitely Maysvillian, points up the possibility of a slight decrease in the age of the faunal assemblage from the north-central to the south-central Appalachians. This would appear to coincide with the expected variations in rate of progradation from east to west throughout Late Ordovician time. It seems that the environments in the more northerly localities throughout the Late Ordovician would be less static and hence only Maysvillian forms have been preserved. The areas in the south, experiencing a considerably diminished and diluted terrigenous influx, would remain environmentally stable for a somewhat longer period of time, perhaps into the Richmondian.

Suborder INTEGRATA
Family AMPLEXOPORIDAE

Genus *AMPLEXOPORA*

Plate 7, figures 3-6; plate 8, figures 1-4

The identification of the genus *Amplexopora* is based upon analysis of seven microsections from southwestern Virginia. The zoaria are ramose and have a median diameter of 12 mm. Zooecial walls are thick and integrate in the exozone and have well-developed laminated zooecial linings. There are a few planar diaphragms regularly spaced within the exozone. Mesopores are absent and acanthopores few.

Assignment of these specimens to the genus *Amplexopora* was aided by the plates and descriptions given by Boardman (1960, p. 16) in his revision of the genus *Am-*

plexopora. Specimens were positively identified only at localities 131 and 138, whereas at locality 141 *Amplexopora* could be tentatively identified only from two specimens which came from an assemblage that had fewer trepostome zoaria, i.e. bryozoan faunal province III (see Fig. 13). *Amplexopora* is found at sites with numerous specimens of *Zygospira recurvirostra, Pterinea* (*Caritodens*) *demissa* and *Ambonychia cultrata,* somewhat less common *Hebertella sinuata,* and fragments of a peronoporid trepostome; all part of the Spiriferid Population of the *Zygospira–Hebertella* Community. The external morphology of *Amplexopora* is no different from that of the other abundant trepostomatous Bryozoa, emphasizing the existence of fairly uniform, quiet water conditions throughout much of the southwestern Virginia and northern Tennessee area during the Late Ordovician.

FAMILY HALLOPORIDAE

GENUS *HALLOPORA*

Plate 9, figures 1-6

Identification of the genus *Hallopora* is based on the analysis of 57 microsections of specimens from southwestern Virginia and northern Tennessee, and 11 microsections from central Pennsylvania. The zoaria are ramose and show a median diameter of 2 mm in southwestern Virginia and northern Tennessee, increasing to 10 mm in central Pennsylvania. Zooecial walls are thick and integrate in the exozone and have laminated zooecial linings. Thin, planar diaphragms are crowded near the exozone. Mesopores are abundant and clustered on monticules, whereas acanthopores are absent.

Hallopora is one of the most characteristic and distinctive Upper Ordovician trepostomes. The assignment of these central Appalachian specimens to this genus was made with the aid of plates and descriptions given by Bassler (1953, p. G112) and Utgaard and Perry (1964, p. 101).

Hallopora is abundant at localities in central Pennsylvania (loc. 34, 34A, 36) and southwestern Virginia-northern Tennessee (loc. 127, 137, 147, 184) and is the most widespread central Appalachian trepostome. *Hallopora* characterizes two quite geographically distinct bryozoan faunal provinces; i.e., provinces I and III (see Fig. 13), and because of this isolation it is possible that these specimens represent two different species. This possibility is further emphasized by significant differences in the associated faunal populations. In central Pennsylvania, crinoids and *Onniella multisecta* occur with lesser numbers of *Hallopora, Rafinesquina* "*alternata*" and *Sowerbyella* (*Sowerbyella*) *sericea,* which are part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. In southwestern Virginia and northern Tennessee, more numerous specimens of *Hallopora* are found in both the Spiriferid and Orthid Populations of the *Zygospira–Hebertella* Community (see Table 13). Furthermore specimens of *Hallopora* from northern Tennessee localities (see Pl. 9, figs. 1 and 4) have been tentatively identified as a form resembling Lower Richmond species in Kentucky, whereas specimens from central Pennsylvania localities do not resemble these forms and may be slightly older. The significance of a slight decrease in the age of the fauna from north to south has been discussed above.

TABLE 13. The associated faunal elements of *Hallopora* in southwestern Virginia and northern Tennessee. The *Hallopora* faunal association in central Pennsylvania is not listed in this table but discussed in the text.

	Clinch Mt., Tenn.	Lone Mt., Big Ridge, Wallen Ridge, Tenn. Cumberland Mt., Clinch Mt., Rich Mt., Va.
Locality numbers	125, 126	127, 128, 132, 137, 147, 184
Associated faunal elements	*Hallopora* *Batostomella* *Zygospira recurvirostra* *Modiolopsis modiolaris*	*Hallopora–Dekayia* *Zygospira recurvirostra* *Pterinea* (*Caritodens*) *demissa* *Hebertella sinuata* *Rafinesquina "alternata"*
Population	Spiriferid	Orthid
Substratum	lime mud	silty mud

BRACHIOPODA
Plates 10-15

Brachiopods are the most numerous and widespread faunal elements in the central Appalachian Upper Ordovician rocks. The phylum is represented by five orders and eight species. There have been only a few recent comprehensive taxonomic reviews of North American Lower Paleozoic Brachiopoda useful to this study; these include Schuchert and Cooper (1932), Salmon (1942), D. Hall (1962) and Williams and Wright (1963). The generic review by Williams et al. (1965) and the studies of predominantly European species by Jones (1928), Bancroft (1928, 1945), Whittington (1938) and Williams (1953, 1962) proved valuable.

Phylum BRACHIOPODA
Class INARTICULATA
Order LINGULIDA
Superfamily LINGULACEA
Family LINGULIDAE

Genus *LINGULA*?
Plate 10, figures 1-5

A small to medium-size linguloid shell (over 150 specimens, averaging 15 mm length) is a widespread and common faunal element throughout the central Appalachian Upper Ordovician strata. Unfortunately preservation is so poor that no internal features are known, and hence the precise generic designation must remain in doubt. The linguloid fossils of the North American Ordovician have usually been referred to *Lingula* or *Pseudolingula,* and Bassler (1919, p. 232) introduced the name *Lingula nicklesi* for specimens in the "*Orthorhynchula* Bed" of south-central Pennsylvania. I have collected from this same general region but at present do not feel that these specimens can be shown to be equivalent to *L. nicklesi* from the Ohio Valley (Bassler, 1919, pl. 57, figs. 1-3, figures specimens only from Cincinnati, Ohio). The following list includes possible subjective synonyms.

Pseudolingula iowensis (Owen, 1894)
P. rectilateratis (Emmons, 1842)
Lingula elderi Whitfield 1880
L. quadrata Hall 1847
L. waynesboroensis Foerste 1910
L. cincinnatiensis (Hall and Whitfield, 1875)
L. nicklesi Bassler 1919

Lingula? is numerous from south-central Pennsylvania to southern Virginia, brachiopod faunal province II (Fig. 14), and is most often found with: 1) *Tancrediopsis cuneata*, *Plectonotus*? sp. and *Ischyrodonta truncata*, 2) by itself, and 3) locally with *Orthorhynchula linneyi*. The first two occurrences characterize the Linguloid Population of the *Orthorhynchula–Ambonychia* Community, whereas the third constitutes a portion of the Rhynchonellid Population of the same community. The rock type ranges from muddy silt to a clean sand, and scattered linguloids have been found in hard orthoquartzitic Oswego sandstones. Linguloids are found higher in the upper Reedsville section than any other species, occasionally occurring alone and in significant numbers only a few feet below the contact with the Oswego Sandstone. Figure 31 outlines the general faunal-stratigraphic relationships.

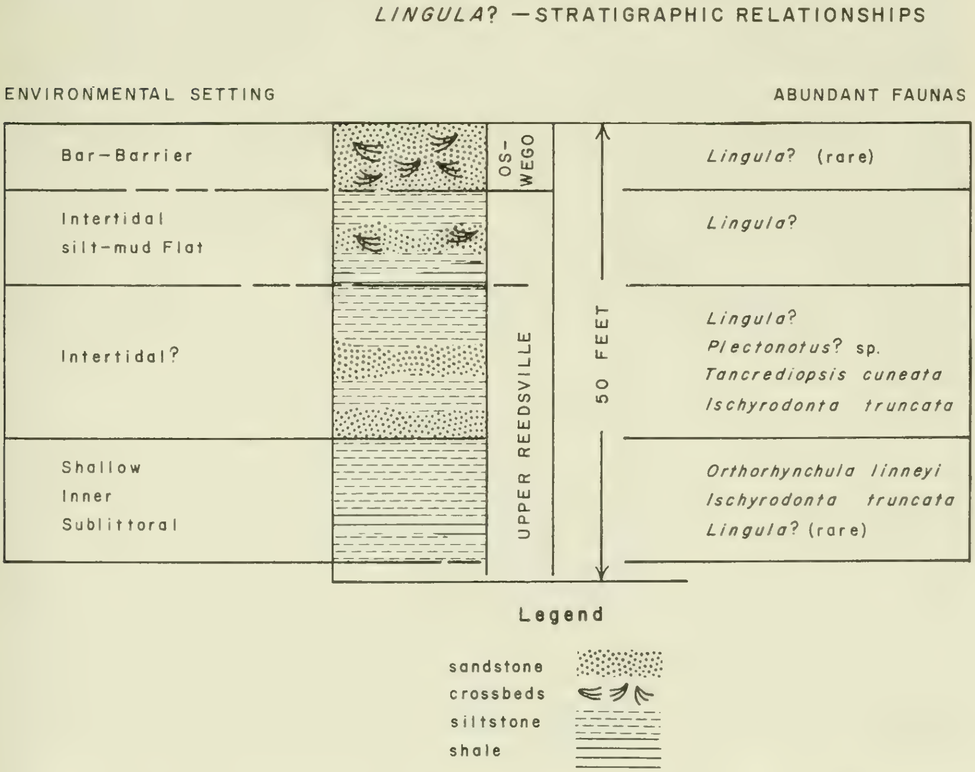
LINGULA? —STRATIGRAPHIC RELATIONSHIPS
ENVIRONMENTAL SETTING
ABUNDANT FAUNAS
Bar–Barrier
Intertidal silt–mud Flat
Intertidal?
Shallow Inner Sublittoral
OS–WEGO
UPPER REEDSVILLE
50 FEET
Lingula? (rare)
Lingula?
Lingula?
Plectonotus? sp.
Tancrediopsis cuneata
Ischyrodonta truncata
Orthorhynchula linneyi
Ischyrodonta truncata
Lingula? (rare)
Legend
sandstone
crossbeds
siltstone
shale

FIG. 31. Associated faunal elements of *Lingula*?. Stratigraphic section is a composite from exposures in south-central Pennsylvania and eastern West Virginia. Lithology schematically presented. *Lingula*? is common only in the environments interpreted as intertidal and silt-mud flat.

The life habits of Recent linguloids, *Lingula* and *Glottidia,* are probably better known than those of any other brachiopods (see Craig, 1952; Hyman, 1959; Rudwick, 1965). Jørgensen (1966, p. 8–10) summarized the suspension feeding mechanism of linguloids. Hyman (1959, p. 589) quotes earlier investigators to the effect that linguloids are very general feeders, their digestive tracts containing a variety of organic and inorganic materials.

Yatsu (1902) has found that Recent linguloids can burrow about a foot below the surface of the substratum and that their pedicle is attached to shell fragments or more consolidated, coarser sediments. I have found definite vertical linguloid burrows in the lower Oswego sandstones, though linguloid burrows need not be vertical. Rudwick (1965, p. H203) felt that this infaunal mode of life was not reflected in any distinctive feature of the shell itself and that many fossil linguloids may have been epifaunal.

The Recent linguloids inhabit shoals, banks, mud-sand flats and beaches; the substratum ranges through muds and coarse sands. Hatai (1940) has found Recent linguloids limited to depths of less than 20 meters with only rare occurrences in deeper waters. Craig (1952, p. 115) added that besides being a shallow water marine animal, the Recent linguloids could probably withstand prolonged periods of brackish water conditions; none have been reported from truly fresh water environments.

Rudwick (1965, p. H212) claimed that few fossil brachiopods could be used as reliable indicators of water depth, with the possible exception of fossil linguloids found without any other associated brachiopods. The latter occurrences could be taken to reflect a possible intertidal environmental setting. I believe that a very nearshore, possibly intertidal, environment is highly likely where linguloids are the single abundant faunal element, and is probable where *Lingula*? occurs with *Tancrediopsis cuneata*, *Plectonotus*? sp. and *Ischyrodonta truncata.* Association with *O. linneyi* probably reflects a shallow sublittoral regime as contrasted to the sheltered mud-silt flats of the other two associations.

One other inarticulate brachiopod, *Schizocrania,* is found in the central Appalachian Upper Ordovician rocks. It is not common, being found at only one locality in a silty mud associated with large *Modiolopsis modiolaris* and a few *Ambonychia praecursa* from the Rynchonellid Population of *Orthorhynchula–Ambonychia* Community (see Table 10). Apparently, it lived in a normal marine, quiet sublittoral environment.

Class ARTICULATA
Order ORTHIDA
Suborder ORTHIDINA
Superfamily ORTHACEA
Family PLECTORTHIDAE
Subfamily PLECTORTHINAE
Genus *HEBERTELLA*

Hebertella sinuata (Hall, 1847)
Plate 11, figures 7-8; plate 12, figures 1-2

Orthis sinuata Hall, 1847, p. 128, pl. 32B, figs. 2a-i, 2k; pl. 32C, figs. 21-s. Meek, 1873, p. 96, pl. 9, figs. 4a-g.

[?]*Orthis subjugata* Hall, 1847, p. 129, pl. 32C, figs. 1a-i, 1k, 1m, 1n.

[?]*Orthis occidentalis* Hall, 1847, p. 127, pl. 32A, figs. 2a-i, 2h, 2l, 2m; pl. 32B, figs. 1a-i. [not] Meek, 1873, p. 96, pl. 9, figs. 3a-h. [not] Hall, 1883, pl. 34, figs. 31-34; pl. 35, figs. 16-21.

Orthis occidentalis var. *sinuata* (Hall). Meek, 1873, p. 98.

Hebertella sinuata (Hall). Hall and Clarke, 1892, p. 222, figs. 1-8. Foerste, 1910, p. 52, pl. 2, fig. 5. Foerste, 1924, p. 110, pl. 10, fig. 11. Butts, 1941, p. 117, pl. 97, figs. 1-4. Cooper, 1944, p. 299, pl. 113, figs. 14-20. Williams and Wright, 1965, p. H324, figs. 205, 5a-e.

Hebertella occidentalis var. *sinuata* (Hall). Cumings, 1908, p. 908, pl. 34, figs. 3, 3a-e. Schuchert and Cooper, 1932, p. 59, pl. 11, figs. 14, 17, 19, 20, 22-26.

[?]*Hebertella occidentalis* (Hall). [not] Hall and Clarke, 1892, p. 222, pl. 5A, figs. 11, 12. [not] Cumings, 1908, p. 906, pl. 34, fig. 4. Foerste, 1910, p. 53, pl. 2, figs. 1a, 1b, 2a, 2b. Foerste, 1924, p. 110, pl. 5, figs. 5a, b; pl. 10, figs. 10a, b. [?] Ruedemann, 1925b, p. 120, pl. 13, figs. 1, 2.

[?]*Hebertella subjugata* (Hall). Foerste, 1910, p. 54, pl. 2, fig. 8. Foerste, 1912, p. 129, pl. 8, fig. 6.

[?]*Hebertella latasulcata* Foerste, 1914b, p. 131, pl. 3, figs. 7a, b.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of moderately large size (median length of 24 specimens, 16 mm; median width of 17 specimens, 23 mm), inequivalved, biconvex, globose, outline subelliptical. Shape only slightly variable, wider than long, greatest width near hinge line, length varying between 62 and 76 per cent of width (median of 12 specimens, 74 per cent). Hinge line long, straight, wide; interarea curved, both valves more or less apsacline. Cardinal angle obtuse; extremities subround. Anterior commissure uniplicate to sulcate; anterior margin broadly curved to flat, or slightly concave; lateral margins subparallel. Multicostellate, costae broad, rounded, numerous; spaces between costae narrow, deep; costellae few, prominent, bifurcation only near valve margins of larger shells; concentric striae faint, very few, widely spaced near valve margins.

Pedicle valve broadly convex, broad sulcus, umbo inflated, beak slightly incurved; delthyrium moderately large, deltidium unknown; delthyrial chamber deep; dental plates extend as elevated ridges anterolaterally to surround ventral muscle scar. Two diductor scars, broad, subcrescentic, not enclosing adductor scar anteriorly; two distinct adductor scars, impression of support on internal mold, double median ridge with shallow central grove; adjustor scars unknown.

Brachial valve sharply convex, wide fold, prominent beak arched over ventral interarea. Notothyrial chamber deep; cardinalia preserved on internal mold; brachiopores at lateral margins of notothyrium, divergent anteriorly, short, pointed. Dental sockets deep. Cardinal process, thick ridge, extends anteriorly part way toward center of valve, myophore prominent. Dorsal muscle scars obscure, two posterior adductors, subovate. Mantle canal system unknown. Shell fibrous, impunctate, possibly endopunctate, irregular pitting of internal surface.

MATERIALS. The description is based on over 45 specimens from central Virginia and northern Tennessee deposited in the Peabody Museum.

Discussion. The assignment of these central Appalachian Upper Ordovician specimens to *Hebertella sinuata* is tentative pending a complete taxonomic review of the North American species of *Hebertella*. *H. sinuata,* the type of the genus proposed by Hall and Clarke (1892, p. 198), comprises a heterogeneous assemblage of orthids. Their definition was subsequently emended by Schuchert and Cooper (1932, p. 59), who should be consulted for outstanding figures of *H. occidentalis* var. *sinuata* (Schuchert & Cooper, 1932, pl. 11, figs. 14, 17, 19, 20, 22-26).

Hall (1847, p. 128), in the original description of *Orthis sinuata,* stated that the misidentification of this and other "similar species" could result from collections of only small amounts of material. He believed that variations related to age were very important. Schuchert and Cooper (1932, p. 60) found that young forms of *Hebertella* could scarcely be distinguished from mature species of *Plectorthis*, either internally or externally.

Within the genus itself uncertainty exists as to assignment of specimens among *H. occidentalis, H. sinuata* and *H. subjugata*. These three eastern North American Upper Ordovician species show only slight differences in external morphology, are commonly listed as occurring at the same horizon (Hall, 1847, p. 130), and have very poorly defined comparative internal features. *H. subjugata* has been usually distinguished from the other two by its finer plications. *H. occidentalis* is supposed to show a slight sulcus near the beak of the brachial valve that distinguishes it from the nonsulcate *H. subjugata* and *H. sinuata*. All previous investigators have admitted that the distinctions are difficult to make. Complete gradations in the shell plications and brachial valve depressions have been noted by Foerste (1910, p. 53) at a number of Upper Ordovician localities in the Ohio River Valley.

Earlier Foerste (1909, p. 224) had described what appears to be a specific difference in the external shell morphology of *Hebertella*; the presence of a pronounced sulcus in the brachial valve, not just a slight depression near the beak. *H. alveata* (cf. *H. alveata* var. *richmondensis*) Foerste 1909 incorporated many of the dorsally sulcate forms that earlier authors had called *Orthis occidentalis*. One of these authors was Meek (1873, p. 98) who remarked that all gradations exist between those specimens that have a well-defined mesial sinus on the dorsal valve (i.e., *H. alveata* Foerste 1909 = *Orthis occidentalis* Meek 1873) and others in which no trace of a sinus can be found [i.e. *H. sinuata* (Hall, 1847)]. Thus it seems that *H. sinuata* must be placed in the category of *nomen inquirendum* pending a restudy of this material.

Very well preserved internal and external molds have been found at a few Upper Ordovician localities in the central Appalachians. A slight mesial sulcus near the beak of the brachial valve has been noted in a few specimens, scattered throughout a number of localities. A distinctive pattern of coarser or finer plications has not been recognized, and none of the extremely sulcate forms have been obtained at any of the central Appalachian localities. The highly sulcate *Hebertella* has been reported only from Upper Ordovician strata of the Ohio River Valley.

Hebertella sinuata is abundant only along the more southeasterly exposures of the Reedsville Formation, south-central Virginia and northern Tennessee, brachiopod faunal province III (see Fig. 14). Specimens tentatively identified by me as *H. sinuata* have been found in the Shochary Ridge Sandstone of eastern Pennsylvania, but generally poor preservation prevents discrimination from *Plectorthis*. Table 14 lists the commonly associated abundant faunal elements, all part of the *Zygospira–Hebertella* Community. Not included on the table are the eastern Pennsylvania localities where questionable *H. sinuata* occurs with two distinctly northern species of brachiopod faunal province I, the numerous *Onniella multisecta* and *Sowerbyella* (*Sowerbyella*) *sericea*, which are part of the *Sowerbyella–Onniella* Community.

TABLE 14. The associated faunal elements of *Hebertella sinuata* in northern Tennessee and sounthwestern Virginia. All brachiopods are part of the *Zygospira–Hebertella* Community.

	Catawba Mt., Vt.	Clinch Mt., Walker Mt., Va.	Powell Mt., Va. Cumberland Mt., Va. & Tenn. Wallen Ridge, Clinch Mt., Tenn.
Locality numbers	177, 179	147, 149, 150	130, 131, 132, 133, 139
Associated faunal elements	*Rafinesquina* "*alternata*" *Zygospira recurvirostra*	*Zygospira recurvirostra* *Pterinea* (*Caritodens*) *demissa* *Hallopora* *Modiolopsis modiolaris* *Orthorhynchula linneyi*	*Zygospira recurvirostra* *Hallopora* *Amplexopora* *Pterinea* (*Caritodens*) *demissa*
Substratum	sand–silt	muddy silts	lime muds

The life habits and environmental setting of *H. sinuata* can be inferred from the few studies of Recent brachiopods, even though there are no living orthids. It is assumed that *H. sinuata* thrived in waters of normal marine salinity and was rooted to the silty substratum by a fairly stout pedicle. Attachment in the normal fashion of articulate brachiopods would allow the heavy shelled form with a much more convex brachial valve to rest on or be partially buried in the substratum, the convexity raising the plane of commissure above the ctenidial-fouling, sediment-laden bottom currents. The patchiness of the distribution even in areas where the shells are abundant is common in the other Upper Ordovician brachiopod species and is characteristic of the gregarious nature of Recent brachiopods. The distinctly globose, trilobate form of *H. sinuata*, superficially much like that of *O. linneyi*, may be indicative of adaptation to more turbulent conditions than that experienced by the other central Appalachian orthids, strophomenids and spiriferids. The functional significance of shape is reviewed in the discussion of *O. linneyi*.

The stratigraphic and geographic evidence points to a quiet, but sporadically turbulent, sublittoral habitat for *H. sinuata*. The overall restriction of the fauna to the south may be explained as a function of currents, rates of sedimentation or temperature control. *H. sinuata* is most common in fine sands and silts and appears to replace *O. linneyi* in southwestern Virginia and northern Tennessee, brachiopod faunal province III, as the dominant inner sublittoral brachiopod species. *H. sinuata*, however, gives way to the smaller atrypid *Zygospira recurvirostra* in finer silts and muds of the same geographic region, possibly indicating more sheltered nearshore regions.

SUPERFAMILY ENTELETACEA
FAMILY DALMANELLIDAE
GENUS *ONNIELLA*

Onniella multisecta (Meek, 1873)
Plate 11, figures 1-6

Orthis multisecta James, 1871, p. 10 (*nomen nudum*). Miller, 1875, p. 22. Sardeson, 1897, p. 97, pl. 4, figs. 20-23.

Dalmanella testudinaria var. *multisecta* Meek, 1873, p. 112, pl. 8, figs. 3a-d, [?]figs. 1a-c. Cumings, 1908, p. 901, pl. 33, figs. 4, 4a-c.

Dalmanella multisecta (Meek). Bassler, 1909, pl. 14, figs. 4-6. Foerste, 1909, p. 217. Bassler, 1919, p. 244, pl. 54, figs. 5, 6. Rudemann, 1925b, p. 117, pl. 12, figs. 1-3. Secrist and Evitt, 1943, p. 367.

[?]*Dalmanella fultonensis* var. *lorrainensis* Ruedemann, 1925b, p. 119, pl. 12, fig. 7.

[?]*Dalmanella fultonensis* var. *rotunda* Ruedemann, 1925b, p. 120, pl. 12, figs. 4-6.

[?]*Dalmanella fertilis* (Bassler). Butts, 1941, p. 113, pl. 96, figs. 3-6.

[?]*Dalmanella emacerata* (Hall). Butts, 1941, p. 114, pl. 96, fig. 16.

Resserella multisecta (Meek). Cooper, 1944, p. 353, pl. 138, figs. 15-18.

Onniella multisecta (Meek). Hall, 1962, p. 148, pl. 20, figs. 11-31.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of small size (median length of 35 specimens, 8 mm; median width of 31 specimens, 11 mm), slightly inequivalved, generally biconvex, outline subcircular. Shape only slightly variable, wider than long, greatest width near midpoint between hinge line and anterior margin, length varying between 76 and 82 per cent of width (median of 23 specimens, 78 per cent). Hinge line short, straight; interarea curved, both valves orthocline or anacline. Cardinal extremities rounded. Anterior commissure rectimarginate to faintly sulcate; anterior and lateral margins broadly rounded. Multicostellate, costae coarse, broad, rounded; costellae prominent, numerous bifurcations especially near shell margins. Concentric striae of two distinct types: coarse, widely spaced, concentrated near valve margins; fine, numerous, over entire surface of valve.

Pedicle valve broadly convex, umbo inflated, broadly rounded, beak erect. Delthyrium prominent, large, triangular; deltidium unknown; delthyrial chamber deep; hinge teeth large, crural fossettes deep, anterior-inner edge of hinge teeth well preserved on latex impression of internal mold (Pl. 11, fig. 2); dental plates small, extend as faint ridges anteriorly to surround posterodorsal portions of ventral muscle scar. Two diductor scars, elongate, flanking but not entirely enclosing a medial adductor scar.

Brachial valve slightly convex, flattened at margins, broadly sulcate. Notothyrial chamber deep, triangular. Cardinalia preserved on latex impression of internal mold (Pl. 11, fig. 3); brachiopores at lateral margins of notothyrium, diverge anteriorly, short, erect, razor-like, thickened at base where fused to medial ridge; fulcral plates unknown. Denticle small, narrow, forms posteriolateral lip of deep socket. Cardinal process small, bilobed, extends anteriorly toward center of valve as thickened medial ridge. Dorsal muscle scars prominent, quadripartite, paired posterior and anterior adductors, subround, anterior scars about twice as large as posterior ones. Mantle canal system unknown. Shell microstructure and mineralogy unknown, preservation as internal and external molds.

Materials. The description is based on over 50 specimens from eastern and central Pennsylvania deposited in the Peabody Museum.

Discussion. These central Appalachian Upper Ordovician specimens are assigned to *Onniella multisecta* on the basis of their consistently small size, subcircular outline, well-defined ventral and dorsal muscle scars and delicate cardinal processes. Misidentification as the similar *O. emacerata* or *O. meeki* was avoided, as *O. emacerata* is a much larger shell with a subrectangular outline and *O. meeki,* although exhibiting a good deal of shape variation, has a prominent large cardinal process which fills the notothyrial chamber of the brachial valve and is visible from the exterior.

The Ordovician dalmanellids are one of the more carefully studied brachiopod groups. Unfortunately there has been a general tendency toward genus-making and nomenclatural error since Hall and Clarke (1892) introduced the genus *Dalmanella,* "Group of *Orthis testudinaria*." Subsequent works of particular note are by Bancroft (1928, 1945), Schuchert and Cooper (1932), and the important summary papers of Hall (1962), and Williams and Wright (1963).

Many of the previous investigators of the eastern North American Upper Ordovician rocks undoubtedly have identified specimens of *O. multisecta* as *Dalmanella* (= *Orthis*) *testudinaria*, a European Ordovician species made the type of the new genus *Dalmanella* by Hall and Clarke (1892, p. 205), but so inadequately defined that it soon came to contain a heterogeneous group of North American dalmanellid species. Sardeson (1897), Raymond (1921) and Foerste (1924) presented an increasingly better documented case for the argument that species agreeing with the type *Dalmanella testudinaria* were unknown to North America. Schuchert and Cooper (1932, p. 126), in their monographic review of the dalmanellid genera, unfortunately disregarded the conventions of zoological nomenclature and replaced the type *Dalmanella* (*D. testudinaria*) with the common North American species *Dalmanella rogata*, which was supposed to be the true representative of a widespread Upper Ordovician North American genus. In the process they placed *Onniella* Bancroft, 1928, in synonymy with the emended *Dalmanella.*

Cooper (1942, p. 229) recognized the error but no longer believed the species in the "*Dalmanella rogata* group" were congeneric with Bancroft's *Onniella* and felt that this latter genus in North America was restricted to a few species of Richmond age. This, of course, left the "*Dalmanella rogata* group" without a valid generic designation. Cooper (1944, p. 251–252) subsequently remedied this when he placed the "*D. rogata* group" in the genus *Resserella*. Unfortunately Schuchert and Cooper (1932, p. 126) had emended the definition of *Resserella* Bancroft and had designated a type that placed it in synonymy with *Parmorthis*; the result of this synonymy was to restrict the term *Resserella* to a group of Silurian specimens and again leave the distinctive "*Dalmanella rogata* group" nameless. Cooper (1956, p. 956) thus introduced the new genus *Paucicrura* with its type *Dalmanella rogata* and presumably included in the new genus all those Upper Ordovician species originally congeneric with *Dalmanella rogata.*

Hall (1962) reviewing the Cincinnatian dalmanellids of the Ohio Valley area, placed *Paucicrura* in synonymy with *Onniella*. Hall (1962, p. 139) cited the works of Opik (1933) and Whittington (1938) in considering the Upper Ordovician species of the "*Dalmanella rogata* group" as belonging to the genus *Onniella*. Hall further stated that *Paucicrura* must be placed in synonymy with *Onniella* since the generic descriptions given by Bancroft (1928, p. 55) and Schuchert and Cooper (1932, p. 120) are identical. Because Schuchert and Cooper considered "*Dalmanella*" and *Onniella* to be congeneric and because there is no description of the type for the genus *Paucicrura* given by Cooper (1956), the earlier definition is the only valid one standing. Williams and Wright (1963, p. 28–29) list quite similar diagnostic features for *Onniella* and *Paucicrura* and found only the undifferentiated bilobed cardinal process in *Onniella* to differ from the differentiated trilobate process in *Paucicrura*. Hall (1962), however, found bi-, tri- and quadrilobate cardinal processes in *Onniella*. Howe and Reso (1967, p. 358) submit a reasonable suggestion: if the wide variation of the posterior portion of the cardinal process in *Paucicrura* can be demonstrated, *Paucicrura* should be placed in synonymy with *Onniella*.

The distribution of abundant *O. multisecta,* limited to eastern and central Pennsylvania, brachiopod province I, shows almost the same zoogeographic pattern (see Table 3) as that of *Sowerbyella* (*Sowerbyella*) *sericea* (see Fig. 14). However, *O. multisecta* becomes suddenly sparse in south-central Pennsylvania; only rare, scattered specimens are found in northern Virginia (loc. 160, 161, 162, 165, 167, 168). The enclosing rock is commonly a mud or muddy silt; the abundant associated faunal elements are *Sowerbyella* (*Sowerbyella*) *sericea* and crinoids, part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. In certain locales *Rafinesquina* "*alternata*", *Hallopora* and *Flexicalymene* are common. Infrequently there occur concentrated patches of *Cryptolithus, Sinuites* and *Receptaculites*. *O. multisecta,* like many of the other central Appalachian Upper Ordovician brachiopods, often occurs in highly concentrated patches where entire bedding planes are covered with this one species.

The life habits and environmental setting of *O. multisecta* are as hard to infer as were those for the other orthids and strophomenids. As in the case of the brachiopods, one can assume a normal marine environment, waters of low turbidity and low but sporadic rates of sedimentation. Temperature may be an important factor, as the species was confined to the northeastern parts of the central Appalachians during the Late Ordovician. *O. multisecta* presumably had a fairly stout functional pedicle by which it was attached to the muddy silt substratum, other shells, or non-preservable material such as worm tubes or algae. Considerable organic stain is evident with the dalmanellids. The patchiness and gregarious nature of *O. multisecta* are common in Recent shelf brachiopod faunas and are also usual in the other Upper Ordovician brachiopod species. Geographic and stratigraphic evidence points to a habitat somewhat north of the major area of terrigenous clastic influx, but in all cases the fauna appears to have been abundant only in the sublittoral, probably outer sublittoral, relatively quiet waters dominated by a few numerous, closely bunched species. This shelf portion appears to be assumed elsewhere by *Zygospira recurvirostra* and some *Hebertella sinuata*, brachiopod faunal province III (see Fig. 14), which replace *O. multisecta* southward.

ORDER STROPHOMENIDA
SUBORDER STROPHOMENIDINA
SUPERFAMILY PLECTAMBONITACEA
FAMILY SOWERBYELLIDAE
SUBFAMILY SOWERBYELLINAE
GENUS *SOWERBYELLA*

Sowerbyella (*Sowerbyella*) *sericea* (Sowerby, 1839)

Plate 12, figures 3-6; plate 13, figures 1-4

Leptaena sericea Sowerby, 1839, p. 636, pl. 19, figs. 1, 2a, [?]2. Hall, 1847, p. 110, pl. 31B, figs. 2a-h; p. 287, pl. 97, figs. 3a, 3a*, 3b. [not] Hall, 1852, p. 59, pl. 21, figs. 1a-e. Billings, 1856, p. 41, fig. 2. Billings, 1863, p. 163, figs. 139a-c. Meek, 1873, p. 70, pl. 5, figs. 3a-e, [?]3f-h.

Strophomena sericea (Sowerby). Conrad, 1840, p. 201. Emmons, 1842, p. 394, fig. 105.1. Owen, 1844, p. 269, pl. 105, fig. 1. Emmons, 1855, p. 199, pl. 11, figs. 6a-f.

[?]*Leptaena sericea* var. *rugosa* Meek, 1873, p. 72, pl. 5, figs. 3f-h.

[?]*Leptaena aspera* James, 1874a, p. 151.

Plectambonites sericea (Sowerby). Shaler, 1876, p. 28. Hall and Clarke, 1892, pl. 15, figs. 25, 27-29, [?]26. Winchell and Schuchert, 1895, p. 414, pl. 32, figs. 10-12. Cumings, 1908, p. 922, pl. 36, figs. 1, 1a-c. Bassler, 1909, pl. 14, figs. 1, 2. Parks and Dyer, 1922, p. 35, pl. 7, figs. 15, 16. Foerste, 1924, p. 113, pl. 13, figs. 2a, b, 3. Ruedemann, 1925b, p. 123, pl. 12, fig. 18.

[?]*Plectambonites sericeus* var. *asper* (James). Ruedemann, 1901, p. 18, pl. 1, figs. 6, 7.

[?]*Plectambonites sericeus* var. *typus* Ruedemann, 1912, p. 91, pl. 4, fig. 6, [?]figs. 3, 4, 5.

[?]*Plectambonites rugosa* var. *clarksvillensis* Foerste, 1912, p. 127, pl. 1, figs. 7a, b, [?]7c; pl. 10, figs. 7a-d.

[?]*Plectambonites rugosa* (Meek). Foerste, 1912, p. 123. Bassler, 1919, p. 255, pl. 54, figs. 31-33. [?]Parks and Dyer, 1922, p. 35, pl. 7, fig. 11. Ruedemann, 1925b, p. 123, pl. 12, figs. 19-21.

[?]*Plectambonites curdvillensis* Foerste, 1912, p. 122, pl. 10, figs. 15a, b.

[?]*Plectambonites punctostriatus* Mather, 1917, p. 38, pl. 1, figs. 15-17.

[?]*Plectambonites rugosus* var. *manitoulinensis* Foerste, 1924, p. 113, pl. 4, figs. 4a-d.

Sowerbyella sericea (Sowerby). Jones, 1928, p. 414, pl. 21, figs. 1-4.

[?]*Sowerbyella sericea* var. *soudleyensis* Jones, 1928, p. 417, pl. 21, figs. 5, 6.

[?]*Sowerbyella rugosa* var. *triradiatus* Butts, 1941, p. 113, pl. 96, fig. 9.

[?]*Sowerbyella* sp. Butts, 1941, p. 113, pl. 96, fig. 10.

[?]*Sowerbyella rugosa* (Meek). Butts, 1941, p. 113, pl. 96, figs. 7, 8. Cooper, 1944, p. 335, pl. 128, figs. 42, 43, [?]41.

[?]*Sowerbyella clarksvillensis* (Foerste). Cooper, 1944, p. 335, pl. 128, figs. 39, 40.

[?]*Sowerbyella curdvillensis* (Foerste). Cooper, 1956, p. 780, pl. 201A, figs. 1-13.

[?]*Sowerbyella punctostriatus* (Mather). Cooper, 1956, p. 792, pl. 205C, figs. 9-25, pl. 206D, figs. 14, 15.

Sowerbyella (*Sowerbyella*) *sericea* (Sowerby). Muir-Wood and Williams, 1965, p. H379, figs. 243, 1a-f.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of moderately small size (median length of 25 specimens, 8 mm; median width of 29 specimens, 14 mm), inequivalved, outline subcircular. Shape variable, wider than long, greatest width at hinge line, length varying between 44 and 66 per cent of width (median of 20 specimens, 54 per cent). Hinge line long, straight. Cardinal angle variable, acute with subalations, usually right angle. Anterior commissure rectimarginate. Anterior margin broadly curved; lateral margins rounded, subparallel only near hingeline. Parvicostellate, costae closely spaced, narrow, rounded; costellae numerous, bifurcating, regularly spaced between costae; median ridge on brachial valve faint to absent. Concentric striae faint, widely spaced but crowded near valve margins.

Pedicle valve strongly convex, margins nearly flat. Umbonal region not pronounced; beak only slightly above level of hinge line, posterior margin almost straight; cardinal area anacline. Apical foramen unknown, deltidium or pseudodeltidium unknown. Ventral muscle scars well-defined, bilobate, bounded posterolaterally by dental plates, anteromedially by ridges diverging from short, median septum; two adductors, small deeply impressed at posterior extreme of muscle scar; two diductors broad, shallow impression, divided into two subequal elements by low ridges (Pl. 12, fig. 5; Pl. 13, fig. 2).

Brachial valve flat to gently concave, noticeably concave near valve margins. Cardinalia simple; crural bases curved, narrow, diverging widely from posterior end of cardinal process. Chilidial plates form well-defined submedial septa, broaden toward anterior, diverge slightly, fused with small socket ridges, flat-lying, flanking median septum (Pl. 12, fig. 4). Mantle canal system preserved on internal mold (Pl. 13, fig. 1) of brachial valve, lemniscant, inequidistributate (Pl. 12, fig. 3). Shell fibrous, pseudopunctate, punctae regularly spaced in rows between costellae.

Materials. The description is based on over 40 specimens from eastern and central Pennsylvania deposited in the Peabody Museum.

Discussion. These specimens from the central Appalachian Upper Ordovician rocks are tentatively assigned to *Sowerbyella* (*Sowerbyella*) *sericea* pending a complete taxonomic revision of *Sowerbyella* (*Sowerbyella*) and *Sowerbyella* (*Viruella*). Previous investigators described and figured species and varieties of *Sowerbyella* (= *Leptaena*; = *Plectambonites*) from numerous localities in the Upper Ordovician strata of eastern North America. Many of these species and their varieties were named on the basis of slight variations in length-width ratios or poorly defined differences in surface sculpture.

The Family Sowerbyellidae and many other Upper Ordovician brachiopod families have been intensely studied for their usefulness as potential stratigraphic indicators or guides. In the process artificial taxa were created for the recognition of minute subdivisions of rock units. Earlier authors attempted to define slight differences between forms of *Plectambonites* and at first produced numerous stratigraphically defined varieties of *P. sericea,* which later investigators made into distinct species. Foerste (1912, p. 127) was one of the few who recognized at an early date the hopelessness of this situation when he attempted to redefine *P. sericea* var. *rugosa* (Meek) from the Cincinnatian strata of the Ohio River Valley. Although I have not attempted an exhaustive survey of the morphological variation that exists within and among the many world-wide species of Ordovician and Silurian *Sowerbyella* which are presently recognized, I have included in the present synonymy those species from the Ordovician of eastern North America that I believe to be likely subjective synonyms of *S.* (*S.*) *sericea* based on a review of previously published plates and descriptions.

Sowerbyella (*Sowerbyella*) *sericea* is abundant only in eastern and central Pennsylvania (brachiopod faunal province I, see Fig. 14). A few specimens are found in northern Virginia (loc. 160, 161, 166, 178), where *S.* (*S.*) *sericea* constitutes only a very scattered, less significant faunal element. Associated faunal elements are *Rafinesquina* "*alternata*" and crinoids, (part of the Strophomenid Population of *Sowerbyella–Onniella* Community), but *S.* (*S.*) *sericea* is just as often found by itself. *Onniella multisecta* and *Hallopora* are less commonly associated faunal elements, and specimens of *Flexicalymene*, *Zygospira concentrica* and *Phragmolites* are rare. *S.* (*S.*) *sericea* is most often found in a muddy silt or fine sand. The distribution throughout Pennsylvania and northern Virginia is notably patchy.

The life habits and environmental setting of *S.* (*S.*) *sericea* must, of course, be inferred from the few studies of living articulate brachiopods and the one possible strophomenid descendant, *Lacazella*. Strophomenid ecology is reviewed in the discussion of *Rafinesquina* "*alternata*", p. 89. *S.* (*S.*) *sericea* adults lived unattached on the sea floor, much like *R.* "*alternata*". Williams (1953, p. 2) stated that the young stages also were probably unattached, the valves resting freely on the muddy silts and sands. A normal marine environment, probably outer sublittoral, in an area of fairly low turbulence is most likely. The reasons for the concentration of *S.* (*S.*) *sericea* immediately to the north of and off the major area of terrigenous clastic influx are not obvious. Possibly it results from the presence of a suitable firm muddy silt substratum and a tolerable temperature regime. The extreme patchiness of the distribution is typical of the Upper Ordovician brachiopods and is well-documented in Recent brachiopod populations. Local current patterns probably accounted for this patchy nature of distribution, as they account for both nutrient distribution and larval dispersal.

Superfamily STROPHOMENACEA
Family STROPHOMENIDAE
Subfamily RAFINESQUININAE
Genus *RAFINESQUINA*

Rafinesquina "*alternata*" (Hall, 1847)
Plate 15, figures 1-6

Strophomena Emmons, 1842, p. 403, fig. 112.2 (*nomen nudum*).
Leptaena alternata Hall, 1847, p. 286, pl. 79, figs. 2f-2l, [not] 2a-2d.
Strophomena alternata (Hall). Emmons, 1855, pl. 17, fig. 2; [?]pl. 11, fig. 3.
[?]*Strophomena alternata* var. *fracta* Meek, 1873, p. 91, pl. 7, figs. 3a-3c.
[?]*Strophomena squamula* James, 1874b, p. 335.
Rafinesquina alternata (Hall). Hall and Clarke, 1892, p. 282, pl. 8, figs. 6, 7, [?]8-11. Hall and Clarke, 1895, pl. 84, [?]figs. 17, 18. Bassler, 1909, pl. 14, fig. 9. Bassler, 1919, p. 265, pl. 57, fig. 8. Foerste, 1924, p. 114, pl. 13, figs. 6a-c. Ruedemann, 1925b, p. 126. Butts, 1941, p. 117, pl. 97, fig. 29.
[?]*Rafinesquina squamula* (James). Hall and Clarke, 1892, p. 283. Foerste, 1914a, p. 264. Bassler, 1919, p. 264, pl. 54, figs. 3, 4; pl. 58, fig. 4.

[?]*Rafinesquina alternata* var. *fracta* (Meek). Cumings, 1908, p. 927, pl. 37, figs. 5, 5a.

[?]*Rafinesquina mucronota* Foerste, 1914a, p. 265, pl. 2, figs. 7a, b. Parks and Dyer, 1922, p. 37. Foerste, 1924, p. 115, pl. 14, fig. 1; pl. 30, fig. 6, 7. Ruedemann, 1925b, p. 129, pl. 12, figs. 16, 17.

[?]*Rafinesquina mucronota* var. *torontonensis* Parks and Dyer, 1922, p. 38, pl. 7, figs. 13, 14, 17.

[?]*Rafinesquina alternata* var. *centristriata* Ruedemann, 1925b, p. 127, pl. 12, figs. 13, 14.

[?]*Rafinesquina alternata* var. *mediolineata* Secrist and Evitt, 1943, p. 363, figs. 13, 14.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of moderately large size (median length of 39 specimens, 23 mm; median width of 25 specimens, 24 mm), inequivalved, concave-convex, U-shaped outline. Shape variable, slightly wider than long, greatest width near hinge line, width varying between 85 and 129 per cent of length (median of 21 specimens, 102 per cent). Hinge line long, straight. Cardinal angle variable, sharply acute with small alations or broadly rounded, obtusely angular. Anterior commissure rectimarginate. Lateral margins subparallel, broadly rounded; anterior lateral margins smoothly curved. Parvicostellate, costae on median part of valve, well-defined, thick; costellae, primary and secondary, bifurcating, highly variable in length, regularly spaced. Concentric striae prominent, two kinds: coarse, widely but regularly spaced; fine, closely spaced, faint.

Pedicle valve convex, very broadly curved; beak prominent, pointed; cardinal area anacline; delthyrium prominent, pseudodeltidium unknown; posteroventral muscle scar small, fan-shaped, faint.

Brachial valve gently concave, flattened near anterior margin; cardinalia fragile, cardinal process small, details unknown, notothyrium prominent. Shell pseudopunctate, punctate, punctae regularly spaced in rows between costellae, preserved on internal mold (Pl. 15, fig. 1).

Materials. The description is based on over 50 specimens from Pennsylvania to Tennessee deposited in the Peabody Museum.

Discussion. These specimens from the central Appalachian Upper Ordovician rocks are tentatively assigned to *Rafinesquina* "*alternata*" pending a complete taxonomic revision of the Upper Ordovician Rafinesquininae. Previous investigators working in the central Appalachians had frequently identified these large, concavo-convex strophomenids with a distinctive costellate pattern as *R.* (= *Leptaena,* = *Strophomena*) *alternata,* or as one of its numerous subspecies. It had become customary to group a wide variety of shells under this term. Foerste (1924, p. 114) commented that the extreme variation in size, outline, convexity and internal structures of this long-ranging Middle to Upper Ordovician species made the catch-all *R. alternata* virtually useless. He informally attempted to restrict *R. alternata* to those large, plate-like Rafinesquininae of the Upper Ordovician (Maysville) in Canada and in doing so placed only Hall's Hudson River Group specimens in synonymy.

Later Salmon (1942, p. 574) emended the definition of *R. alternata* in her study of the Mohawkian Rafinesquininae. Her emended description is based only on Hall's

New York Middle Ordovician (Trenton)- specimens, and she suppresses the term *R. alternata* in favor of *R. trentonensis.* In the discussion of *R. trentonensis,* Salmon states that the Upper Ordovician (Cincinnatian) forms previously called *R. alternata* do not conform to the emended definition. These later forms are larger, much more convex, and have much less regular costellae. Interior structures are supposed to be more prominently displayed in the Upper Ordovician specimens, but Salmon does not elaborate on the details. She concludes that these specimens very closely resemble *R. alternata* var. *ponderosa* (Hall).

Salmon's (1942, p. 575) informal designation of all Cincinnatian forms previously called *R. alternata* as *R. ponderosa* is not satisfactory. There are numerous references (see Bassler, 1915, p. 1085) to Upper Ordovician (Maysville) specimens, called *R. alternata* (Hall), *R. alternata* var. *fracta* (Meek) and *R. alternata* var. *centristriata* Ruedemann, which do not resemble *R. alternata* var. *ponderosa,* but rather show closer affinity to *R. trentonensis* (Salmon, 1942, emend.). The material I have collected from the central Appalachian Upper Ordovician also appears to be much more similar to *R. trentonensis* than to *R. ponderosa,* although undoubted *R. ponderosa* has been identified from one locality (loc. 97).

However, use of the term *R. trentonensis* for my central Appalachian Upper Ordovician specimens seems a poor choice: first, because Salmon (1942, p. 573) stated that the Upper Ordovician *Rafinesquina* are not conspecific with those of the Middle Ordovician and second, because her emended definition does not include Hall's New York Hudson River Group (Upper Ordovician) *R. alternata,* which the central Appalachian Upper Ordovician specimens closely resemble. The term *R. alternata* must therefore be placed in the category of *nomen inquirendum,* and I will call the specimens from the Upper Ordovician of the central Appalachians *R.* "*alternata*".

The term *R. alternata* var. *mediolineata* was introduced by Secrist and Evitt (1943, p. 363) for specimens found at Massanutten Mountain, north-central Virginia. I have re-collected from their locality (my locality 167) and have found these specimens to exhibit a prominent median costae much like the New York *R. alternata* var. *centristriata* Ruedemann. I am tentatively placing both these taxa in *R.* "*alternata*", because in all other external morphological features these specimens are similar to the other central Appalachian specimens.

Rafinesquina "*alternata*" is widespread throughout the central Appalachian Upper Ordovician rocks but is most abundant from Pennsylvania to northern Virginia, brachiopod faunal province I (see Fig. 14). It is patchy in its distribution in eastern Pennsylvania (Shochary Ridge), West Virginia and southwestern Virginia. Table 15 lists the associated faunal elements of *R.* "*alternata*" in each region, including populations of the *Sowerbyella–Onniella* Community and the *Zygospira–Hebertella* Community. *R.* "*alternata*" occurs alone or with the strophomenid *Sowerbyella* (*Sowerbyella*) *sericea* and crinoids in the Strophomenid Population of the *Sowerbyella–Onniella* Community which is by far its most common association. Most specimens of *R.* "*alternata*" are found in a muddy silt or fine sand.

Any interpretations of the life habits of *R.* "*alternata*" are hindered not only by our lack of knowledge of the anatomy and ecology of almost all Recent articulate brachiopods, but also by the fact that there are no living representatives of the strophomenids with the possible exception of the thecideid *Lacazella* (Williams, 1953). Elliott (1965, p. H857) believed that the affinities of the order Thecideidina must

TABLE 15. The associated faunal elements of *Rafinesquina* "*alternata*" from eastern Pennsylvania to northern Tennessee.

	Shochary Ridge, Pa.	Raccoon Mt., Nittany Mt., Tuscarora Mt., Pa.	North Mt., Massanutten Mt., Va.	Catawba Mt., Va.	Big Ridge, Lone Mt., Wallen Ridge, Tenn. Garden Mt., Va.
Locality numbers	4, 15, 28	31, 35, 37 104, 108	160, 166 167, 168	177, 178	127, 128 136, 183
Associated faunal elements	*Sowerbyella sericea* *Onniella multisecta*	Crinoids *Sowerbyella sericea* *Hallopora*	(very sparce) *Sowerbyella sericea* *Onniella multisecta*	*Hebertella sinuata* *Sowerbyella sericea* Crinoids *Zygospira recurvirostra*	*Hebertella sinuata* *Zygospira recurvirostra* *Hallopora* *Dekayia*
Population	Strophomenid			Orthid	
Substratum	sand–silt				muddy silts–lime muds

remain uncertain pending a complete restudy of *Lacazella,* which lives permanently cemented to the substratum by its large, convex ventral valve with the much smaller dorsal valve uppermost (Hyman, 1959, p. 585). Williams (1953) and Rudwick (1965) emphasized the characteristic shell modifications of the strophomenids. The loss of a functional pedicle as shown by the small size of the foramen is critical to any environmental reconstructions. More recent studies by Crickmay (1966, p. 503), who sectioned Upper Ordovician specimens of *R.* "*alternata*" from Ohio, point up the possibility that the apical cavity had no primal opening at all. Whether the pedicle was atrophied early in life or was never functional, the mature shell must have lain free on the substratum. An adaptation to a soft substratum is seen in the concavo-convex shell form which probably developed concurrently with the loss of the pedicle.

All modern articulate brachiopods are limited to waters of normal marine salinity and appear to be tolerant of some turbulence, but less tolerant of actual sediment influx. *R.* "*alternata*" probably was no exception, as it lived on a muddy fine-grained sand and silt substratum, supported only by the gently convex ventral valve. The environmental setting of *R.* "*alternata*" and the other abundant strophomenid, *Sowerbyella* (*Sowerbyella*) *sericea,* was probably quiet water and sublittoral. Both animals would have had considerable difficulty in maintaining themselves unattached where wave or current energies were high. The strophomenid shape is suggestive of some Recent bivalve molluscs; for example, some of the free-living plano-convex pectinoids, such as *Aequipecten irradians* which inhabits enclosed waters where the substratum is soft mud or firm (not shifting) sand (Gutsell, 1931, p. 573). Perhaps a better bivalve analogue is the Recent East Indian anomiid *Placuna placenta* (Hornell, 1909, p. 45–47), which lies freely on the muddy silts in sheltered or quiet water environments. It is strongly concavo-convex and reportedly lies with its hinge line submerged in the sediment; it is extremely common in a muddy silt community.

ORDER RHYNCHONELLIDA
SUPERFAMILY RYNCHONELLACEA
FAMILY RHYNCHOTREMATIDAE
SUBFAMILY ORTHORHYNCHULINAE
GENUS *ORTHORHYNCHULA*

Orthorhynchula linneyi (James, 1881)
Plate 13, figures 5-8; plate 14, figures 1-5

Orthis(?) *linneyi* James, 1881, p. 41. Nettleroth, 1889, p. 41 pl. 34, figs. 7-13.

Orthorhynchula linneyi (James). Hall and Clarke, 1893, p. 181, pl. 56, figs. 10-13, 19 (13 labeled as 18). Bassler, 1909, pl. 14, figs. 10-12. Foerste, 1910, p. 24, pl. 3, fig. 10. Foerste, 1912, p. 132, pl. 11, fig. 5. Bassler, 1919, p. 271, pl. 57, figs. 9-12. Ruedemann, 1925b, p. 131, pl. 13, fig. 6. Schuchert and Cooper, 1932, p. 42, pl. 16, figs. 12 ,17, 28-30. Butts, 1941, p. 117, pl. 97, figs. 14-19; p. 119, pl. 97, figs. 39-42. Cooper, 1944, p. 309, pl. 117, figs. 41-47. Cooper, 1956, p. 669, pl. 128F, figs. 32-36. Ager et al., 1965, p. H557, figs. 423.2a-f, 425.3a-c.

Platystrophia ponderosa var. *stevensoni* Grabau, 1913, p. 453, pl. 12, figs. 1-3.

Orthorhynchula stevensoni (Grabau). Cooper, 1944, p. 309. Swartz, 1948, p. 111. Swartz, 1955, p. 82. Horowitz, 1965, p. 10.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of moderately large size (median length of 75 specimens, 19 mm; median width of 110 specimens, 23 mm), inequivalved, subpentagonal. Shape variation negligible, slightly wider than long. Cardinal extremities sub-round. Anterior commissure sulcate. Radial costae pronounced, broadly rounded; interspaces deep, sharply rounded.

Pedicle valve broadly convex, medial sulcus prominent. Umbo very prominent, broad, large, elongate; umbonal region inflated, slopes to cardinal extremities steep. Beak erect, curved; beak ridges prominent, preserved on internal mold. Pedicle foramen medium sized, subangular in outline, deltidial plates unknown. Teeth ridge elevated, blunt. Interarea apsacline; hinge line short, straight.

Brachial valve sharply convex, medial fold prominent. Cardinalia preserved on latex impression of internal mold (Pl. 13, fig. 6), functions as crural base; cardinal process simple vertical blade; sockets narrow, elongate, curved anterolaterally from cardinal process; outer socket ridge high, thin; crura prominent, elongate, fusion with dorsal septum. Musculature unknown. Shell calcite, fibrous with conical markings on inner shell surface, preserved on internal mold.

Materials. The description is based on over 900 specimens from south-central Pennsylvania to northern Tennessee deposited in the Peabody Museum.

Discussion. These specimens from the central Appalachian Upper Ordovician rocks are tentatively assigned to *Orthorhynchula linneyi* pending a more complete taxonomic study. *Orthis*(?) *linneyi* was originally described, but not figured, by James (1881) from specimens from the upper part of the Cincinnati Group in Kentucky. The definition was emended by Hall and Clarke (1893, p. 181), who designated it the type of the new genus *Orthorhynchula*. Since that date *Orthorhynchula linneyi* has been identified by numerous investigators from the Middle Ordovician (Trenton) in Kentucky and Tennessee and the Late Ordovician (Cincinnatian) of the Mid-Continent and central Appalachians.

Specimens of *O. linneyi* have undoubtedly been misidentified as the superficially similar *Rynchotrema capax* or *Platystrophia ponderosa*, although neither of these has the short, straight hinge line or well-defined crura* characteristic of *O. linneyi*. Hall and Clarke (1893, p. 182) and Foerste (1910, p. 25) thought that *O. linneyi* was a characteristic fauna of the south-central Appalachians and was not found north of southwestern Virginia, but Ulrich (1911), Bassler (1919) and Butts (1940) identified *O. linneyi* as a major faunal component of the Upper Ordovician strata throughout the central Appalachians. Swartz (1948, p. 111) renewed the claim that "*O. linneyi*" previously identified from central Pennsylvania to southwestern Virginia was not identical to the typical *O. linneyi* from Kentucky and Tennessee; therefore, he used the term *O. stevensoni*. This name had been introduced by Grabau (1913, p. 453) as a variety of *Platystrophia ponderosa*, which it most certainly is not. Unfortunately Swartz has not attempted to document the specific differences between *O. linneyi* and *O. stevensoni* (Swartz, 1948, p. 111; 1955, p. 82). Horowitz (1965, p. 10, 91) comments that *O. stevensoni* evolved from the earlier (i.e., Middle Ordovi-

*The crura are two processes that extend from the cardinalia forming the posterior basal support for the spirolophous lophophore.

cian) *O. linneyi*, but again there is no mention of what evolutionary adaptations have taken place. I have re-collected from Grabau's *Platystrophia ponderosa* var. *stevensoni* type locality in Walker Mountain (my locality 151) and have found these brachiopods similar to all the other *Orthorhynchula* specimens in the central Appalachian Upper Ordovician rocks. A restudy of this central Appalachian and Mid-Continent material should remove *O. stevensoni* from the category of *nomen inquirendum*.

The classification of rhynchonellid brachiopods is reviewed by Cooper (1959) and summarized by Ager et al. (1965). Schuchert and Cooper (1932, p. 26, 42) referred very briefly to *O. linneyi* in their classical study of the orthids and pentamerids, making a small but important revision of Hall and Clarke's 1893 definition. More important are their figures of *O. linneyi* from the Maysvillian of Kentucky (Schuchert and Cooper, 1932, pl. 16). Compared to the central Appalachian form, the Upper Ordovician specimens from Kentucky are about one-fourth to one-third smaller and somewhat less ovate, but specific differences in the cardinalia appear slight (see also Foerste, 1910, p. 27; Ager et al., 1965, figs. 425.3a, b and Pl. 13, fig. 6, this paper).

The most distinctive parts of the rhynchonellid brachiopod shell are the crura, which are moderately long and assume several distinctive patterns or shapes (Cooper, 1959, p. 7). Unfortunately the crura of many of the Paleozoic genera have yet to be described and figured. The preservation of much of the central Appalachian Upper Ordovician material as steinkerns and the lack of sufficient numbers of serial sections through the shell have prevented an accurate definition of the crura, although a few latex impressions of the internal mold of the brachial valve do give some indication of overall size and shape (Pl. 13, fig. 6). Ager et al. (1965, p. H553), however, claim that the morphology of the crura does not seem as valuable in the classification of the Paleozoic rhynchonellids as it is in the Mesozoic and Tertiary species. Unfortunately, there is very little agreement on which morphological features are the most important. Not only does each investigator appear to prefer to employ his own techniques for identification of features, but these features are usually only those which he views as important. Ager et al. (1965, p. 552) have pictured a bleak future of a proliferation of Paleozoic rhynchonellid genera if the trend is not reversed. Cooper (1959), however, has provided a valuable summary of rhynchonellid classification and also has reviewed the morphological characters that should be considered in the definition of any rhynchonellids.

Orthorhynchula linneyi is one of the most characteristic and abundant fossils in the central Appalachian Upper Ordovician strata. Bassler (1919, p. 272) felt that this species was so well-represented at the Fairview-Maysville horizon in the Appalachian Valley and Ridge Province that he applied the name "*Orthorhynchula* Bed" to these rocks. They are mentioned in numerous subsequent publications as the *Orthorhynchula* Zone of the Reedsville or Martinsburg Formation. Butts et al. (1939, p. 26), Butts (1940, p. 208) and Butts (1945, p. 5) reported that *O. linneyi* could be found from Morristown, Tennessee to Tyrone, Pennsylvania. I have found *O. linneyi* most abundant along the westernmost exposures of the Reedsville Formation from southwestern Virginia to south-central Pennsylvania, especially in brachiopod faunal province II, but specimens also may be common in province III (Fig. 14). It is more scattered and noticeably less abundant away from these areas in the central Appalachians; Ruedemann (1925b, p. 131) has found only one specimen in western New York, and neither Parks and Dyer (1922) nor Foerste (1914a, 1924) has mentioned it as occurring in the Upper Ordovician rocks of southeastern Canada.

The central Appalachian *O. linneyi* is associated with two distinct faunal populations, i.e., the Rhynchonellid Population of the *Orthorhynchula–Ambonychia* Community and the Orthid Population of the *Zygospira–Hebertella* Community (Fig. 14), and is found in sediments ranging from sands to lime muds. *O. linneyi* is, however, most abundant in slightly muddy sands and silts. Table 16 diagrams the associated faunal elements of *O. linneyi.*

The life habits and environmental setting of the central Appalachian Upper Ordovician specimens of *O. linneyi* can be inferred from the sparse amount of data that has been accumulated on existing genera of rhynchonellids. Hyman, (1959, p. 580), in a brief summation of the work done on Recent Rhynchonellacea, pointed out that the anatomy and shell morphology of some of the genera are fairly well known, but there is little data pertaining to the environmental setting of the rhynchonellids. The overall environmental setting of these Upper Ordovician brachiopods is summarized in the chapter on paleoautecology, p. 36.

The Recent rhynchonellids are characterized by a strong elongate pedicle, spirolophous lophophore, and prominent sulcus and fold. Morse (1902, p. 334) claimed that the unrolled arm tip of the lophophore could actually be extended beyond the margins of the shell. Spicules in the lophophore probably provided support for the extension. *Hemithyris psittacea,* anatomically one of the best known Recent species, has been dredged by Remy (1928) near Jan Mayen Island in the Greenland Sea where in one clump 100 *H. psittacea* had been attached to each other or to pebbles. *H. psittacea* has been found at depths to 2200 meters (Hyman, 1959, p. 599), but is the characteristic circumarctic and circumboreal shelf brachiopod. Hertlein and Grant (1944) have found that the cosmopolitan *H. psittacea* descends into Puget Sound and onto the Oregon coastal waters; DuBois (1916), working in the same area, reported *H. psittacea* to have its maximum abundance from 54 to 160 meters water depth. Thus rhynchonellids form a characteristic shelf fauna, inhabiting quiet water at moderate depths in the outer sublittoral.

O. linneyi is common in the central Appalachian sands and silts and may have been clumped over an extensive area of the inner sublittoral shelf. Between the layers with thickly crowded articulated valves are layers with scattered individuals, possibly indicating some post-depositional reworking or variable rates of deposition, or perhaps representing Late Ordovician distributions which were actually fairly patchy. At a few localities in West Virginia the highest stratigraphic occurrence of *O. linneyi* is marked by worm tubes covering the surface of some valves (Pl. 14, fig. 4). A study of Recent worm borings along the Dutch tidal flats by Boekschoten (1966) has shown occasional concentrated patches of highly bored, loose *Cardium edule* shells that had been washed shoreward along the flats. The less common occurrence of worm tubes at the inhalant openings of *O. linneyi* suggests that a few of these were in living position along the shell bank (Pl. 14, fig. 1). Boekschoten (1966, p. 354) has likewise reported that only 6 per cent of the *Cardium edule* shells show specific borings at only the inhalant opening, and he believes that this sort of occurrence documents infestation in living position. The worm-encrusted *O. linneyi* shells represent the nearest-shore occurrence of this rhynchonellid. *O. linneyi* was probably never intertidal, but apparently could tolerate periods of high sediment influx. The apparent strength of

TABLE 16. The associated faunal elements of *Orthorhynchula linneyi* in south-central Pennsylvania, eastern West Virginia and southwestern Virginia.

	Wills Mt., Jacks Mt., Tussy Mt., Shade Mt., Pa.	North Fork Mt., Va. and W. Va.	Clinch Mt., Walker Mt., Garden Mt., Va.
Locality numbers	63, 78, 112, 98, 99, 87, 111	199, 201, 202, 203	147, 150, 149, 184, 181
Associated faunal elements	alone or with *Ischyrodonta truncata*	*Ischyrodonta truncata* *Ambonychia praecursa* occasionally { *Modiolopsis modiolaris*, *Dekayia*, *Lingula*? }	*Hebertella sinuata* *Ambonychia cultrata* occasionally { *Modiolopsis modiolaris*, trepostomatous Bryozoans, *Zygospira recurvirostra* }
Population	Rhynchonellid		Orthid
Substratum	sand–silt	muddy silt–silt	muddy silt

the pedicle and the prominent zig-zag valve edges may have provided the necessary support and efficient protective sensory device for this rhynchonellid to exist in a turbulent environment. Rudwick (1964) claimed that the presence of a zig-zag commissure did not imply any special environmental conditions. But judging from the abundance of *O. linneyi* in the silts and sands, the zig-zag opening could be an advantage. This type of opening is also found in *Hebertella sinuata,* which replaces *O. linneyi* to the south in the muddy silts and sands.

There are only minor changes in the shape of the *O. linneyi* shell from West Virginia to northern Tennessee. The larger, more rounded shape in the north gives way to a more elliptical and smaller shell in the south, this change coinciding with a dramatic change in the abundant faunal elements. *O. linneyi* is much less common in the lime muds of the south than in the sands and silts of the north. Thus change in shape may be directly related to local environmental controls. Ager (1965) and Rudwick (1965) discuss some aspects of brachiopod morphology as it relates to the type of substratum, but little is actually known about the adaptive morphology of brachiopods. DuBois (1916) has conducted the only successful experiments on phenotypic variation in brachiopod shells as related to current energy. He found that the valves of *Terebratalia transversa* became shorter and more convex where currents were consistently stronger. Unfortunately this type of experimentation has not been continued. It would appear that the more convex northern forms of *O. linneyi,* abundant in the sands and silts, had been subjected to consistently stronger current energies than the ones in the lime muds of the south.

The overall distribution of *O. linneyi* and its possible mode of dispersal have been briefly touched upon by Ulrich (1911, p. 514), Ruedemann (1925b, p. 131–132) and Horowitz (1965, p. 93), who agree that *O. linneyi* is found only in Tennessee and Kentucky in the Middle Ordovician. It appears to have migrated northward during the Late Ordovician along the western edge of the central Appalachians as far north as central Pennsylvania, with a few scattered occurrences in New York. Horowitz (1965) also believed that the rates of evolution were rapid enough for the change of *O. linneyi* into a distinct Late Ordovician species, *O. stevensoni.*

ORDER SPIRIFERIDA
SUBORDER ATRYPIDINA
SUPERFAMILY ATRYPACEA
FAMILY ATRYPIDAE
SUBFAMILY ZYGOSPIRINAE
GENUS *ZYGOSPIRA*

Zygospira modesta (Hall, 1847)

Plate 14, figures 6-7

Producta modesta Say, MS (*nomen nudum*).

Atrypa modesta Hall, 1847, p. 141, pl. 33, fig. 15; p. 289. Emmons, 1855, p. 192, pl. 10, fig. 15.

Zygospira modesta (Hall). Hall, 1862a, p. 154, figs. 1, 2. Hall, 1867, p. 267, fig. 12. Meek, 1873, p. 125, pl. 11, figs. 4a-d. Hall and Clarke, 1893, p. 155, figs. 146-149; pl. 54, figs. 8-10, 12, [?]7. Winchell and Schuchert, 1895, p. 467, pl. 34, figs. 42-

44. Cumings, 1908, p. 946, pl. 36, figs. 8, 8a-i. Foerste, 1910, p. 29, pl. 2, figs. 15a, b. Bassler, 1919, p. 274, pl. 54, figs. 20-22; pl. 57, figs. 13-16. Parks and Dyer, 1922, p. 40, pl. 7, figs. 19, 22. Foerste, 1924, p. 127, pl. 10, figs. 21a, b. Ruedemann, 1925b, p. 133, pl. 13, fig. 16. Butts, 1941, p. 118, pl. 97, fig. 28. Secrist and Evitt, 1943, p. 367. Cooper, 1944, p. 317, pl. 120, fig. 72. Boucot et al., 1965, p. H634, fig. 518.2a.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of small size (median height of seven specimens, 6 mm; median width of five specimens, 8 mm), slightly inequivalved, inflated, biconvex, outline elliptical. Shape variation negligible, slightly wider than long, greatest width near midpoint between hinge line and anterior margin. Hinge line short, straight; interarea of both valves, slightly anacline. Cardinal extremities broadly rounded. Anterior commissure uniplicate to strongly sulcate; anterior margin flattened, lateral margins broadly rounded. Costellate, costae subangular, prominent, numbering about 20; costellae faint, one dorsal, arising from bifurcation of median costae, at anterior margin.

Pedicle valve sharply convex, umbo carinated, broad; beak erect, incurved; pronounced fold umbo to anterior margin, margin moderately concave, four costae on fold, inner two larger; foramen unknown, deltidial plates unknown. All internal features of ventral valve unknown.

Brachial valve broadly convex; sulcus deep, margins convex; three costae in depression, central one large, prominent, flanked by faint, thin costae. All internal features of dorsal valve unknown. Shell microstructure and mineralogy unknown.

Materials. The description is based on about 20 specimens from central Pennsylvania and northern Virginia deposited in the Peabody Museum.

Discussion. The assignment of these central Appalachian Upper Ordovician specimens to *Zygospira modesta* is tentative pending a complete taxonomic review of the North American Lower Paleozoic atrypids. *Z.* (= *Atrypa*) *modesta* was first described and figured by Hall (1847), who subsequently (Hall, 1862a) designated it as the type of the genus *Zygospira*. It is the most common and widespread North American Upper Ordovician *Zygospira* and, I believe, has been occasionally confused with *Z. recurvirostra* and *Z. cincinnatiensis*.

The confusion between *Z. recurvirostra* and *Z. modesta* is reviewed in the discussion of *Z. recurvirostra*, p. 99. *Z. cincinnatiensis*, as originally defined by Meek (1873, p. 126) and elaborated upon by Foerste (1910, p. 29), is quite distinct from *Z. modesta* and is not just a larger form, as many investigators have implied. The much coarser, broadly bifurcating costae and the notably elongated anterior margin at the fold and sulcus are, at least, specifically distinct.

Zygospira modesta is found only in central Pennsylvania and northern Virginia, brachiopod faunal province I (see Table 3; also Fig. 14) and is never as abundant as the congeneric *Z. recurvirostra* in the south, brachiopod faunal province III. In central Pennsylvania *Z. modesta* is found in a fine silt to muddy silt, usually with crinoids and at some locales *Isotelus* and *Flexicalymene*, part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. Rare specimens occur in northern Virginia with *Sowerbyella* (*Sowerbyella*) *sericea* and *Rafinesquina* "*alternata*". It is found as far south as central Virginia (loc. 177, 178) where there are a few specimens in a fine silt-sand dominated by *Hebertella sinuata* of the Orthid Population of the *Zygospira–Hebertella* Community.

Z. modetsa may have differed very little from *Z. recurvirostra* in life habits and environmental setting, and both probably occupied an outer sublittoral regime. The geographic location, brachiopod faunal province I (Fig. 14), and stratigraphic position (Fig. 15) of *Z. modesta* emphasize its outer sublittoral habitat on a muddy silt bottom (see p. 84 and 91 for environmental interpretations of the stratigraphically higher orthids and strophomenids in central Pennsylvania).

Another species of *Zygospira* has been identified in east-central Pennsylvania, brachiopod faunal province I (loc. 120). It is *Z. concentrica* (Ulrich, 1897, p. 14; see Ruedemann, 1925b, p. 134), which is very rare in a black to gray muddy silt dominated by *Onniella multisecta*, *Cryptolithus* and a few specimens of *Sinuites* and *Sowerbyella* (*Sowerbyella*) *sericea*, part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. This association and the substratum type again seem to indicate a quiet, outer sublittoral environmental setting.

Zygospira recurvirostra (Hall, 1847)
Plate 14, figures 8-9

Atrypa recurvirostra Hall, 1847, p. 140, pl. 33, figs. 5a-d. Emmons, 1855, p. 191, pl. 10, figs. 5a-d.

Rhynchonella recurvirostra (Hall). Billings, 1863, p. 168, fig. 152.

[?]*Zygospira modesta* var. *kentuckiensis* James, 1878, p. 7.

[?]*Zygospira kentuckiensis* (James). Nettleroth, 1889, p. 138, pl. 34, figs. 21-25. Hall and Clarke, 1893, p. 157, pl. 54, figs. 11, 15, 16. Foerste, 1924, p. 127, pl. 10, figs. 20a-c; pl. 15, figs. 1, 2a-b, 4a-c. Butts, 1941, p. 117, pl. 97, figs. 5-7. Cooper, 1944, p. 317, pl. 120, figs. 54, 55.

Zygospira recurvirostra (Hall). Hall and Clarke, 1893, p. 157, pl. 54, figs. 1-6. Beecher and Schuchert, 1893, p. 77, pl. 10, figs. 7-21. Schuchert, 1893, p. 82, pl. 11, figs. 1-10, Winchell and Schuchert, 1895, p. 466, pl. 34, figs. 38-41. Ruedemann, 1901, p. 27. Weller, 1903, p. 161, pl. 10, figs. 23-26. Bassler, 1909, pl. 7, figs. 4-5. Foerste, 1914b, p. 132, pl. 1, figs. 2a-c. Bassler, 1919, p. 272, pl. 42, figs. 9-12. Butts, 1941, p. 99, pl. 92, [?]fig. 10; p. 100, pl. 92, fig. 23; p. 118, pl. 97, figs. 34-38. Cooper, 1944, p. 317, pl. 120, fig. 56. Cooper, 1956, p. 673, pl. 142H, figs. 34-38. Boucot et al., 1965, p. H364.

[?]*Zygospira meafordensis* Foerste, 1924, p. 128, pl. 15, figs. 3a-c.

[?]*Zygospira recurvirostra* var. *aequivalvis* Twenhofel, 1927, p. 214, pl. 19, figs. 10-12.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of small size (median length of 13 specimens, 8 mm; median width of 9 specimens, 9 mm), slightly inequivalved, biconvex, inflated, outline subcircular. Shape variation negligible, length and width almost equal, greatest width near midpoint between hinge line and anterior margin. Hinge line short, straight; interarea of both valves orthocline. Cardinal extremities rounded. Anterior commissure sulcate to uniplicate; anterior margin flattened, lateral margins broadly rounded. Costellate, costae subround, well-defined, numbering 19 to 24; costellae, one dorsal, two ventral, arising from bifurcation of median costae, near anterior margin, more pronounced on ventral fold.

Pedicle valve sharply convex; umbo carinated, narrow; beak erect, incurved; pronounced fold, extending umbo to anterior margin, margins moderately concave, four costae on fold, two on slopes of fold. Foramen mesothyridid, deltidial plates conjunct. All internal features of ventral valve unknown.

Brachial valve broadly convex; sulcus wide, flattened, margin slightly convex to flattened, three costae in depression, two on flanks of depression. All internal features of dorsal valve unknown. Shell fibrous, calcite.

MATERIALS. The description is based on about 30 specimens from southwestern Virginia and northern Tennessee deposited in the Peabody Museum.

DISCUSSION. The assignment of these central Appalachian Upper Ordovician specimens to *Zygospira recurvirostra* must be considered tentative pending a more complete taxonomic survey of the North American Lower Paleozoic atrypids. The central Appalachian material does not preserve any internal structures and has permitted comparisons to be made only on external configuration. Species of *Zygospira* have, however, been previously defined primarily on the basis of size, shape and ornamentation. The taxonomic significance of these characters in *Zygospira* has yet to be critically explored.

Zygospira recurvirostra has long been confused with *Z. modesta,* a very common Upper Ordovician species, which is the type of *Zygospira. Z. recurvirostra* has been previously distinguished from *Z. modesta* by its broader, more shallow mesial depression in the brachial valve, and the five equisized primary costae within the depression (Foerste, 1914b, p. 132; Cooper, 1956, pl. 142H; cf. Pl. 14, fig. 8 in this paper). *Z. modesta,* although about the same size as *Z. recurvirostra* and exhibiting the same total number of costae (about 20), has a much more pronounced, deeper mesial sulcus; the costae within the depression are notably more angular, and of the five costae within the depression the medial one is considerably broader than those on either side, which are characteristically faint (Pl. 14, fig. 7).

The central Appalachian Upper Ordovician specimens can be segregated into what appear to be internally consistent species groups on the basis of this mesial depression. Some criteria previously employed in discriminating between the two groups were found to exist in both. The total number of costae was not significantly different between the species, and the bifurcation of one or two medial costae near the anterior margin occurs in both. This bifurcation of medial costae was previously thought to be diagnostic of *Z. cincinnatiensis* (Foerste, 1910, p. 31), but appears to be common throughout the genus *Zygospira.* Meek (1873, p. 126), Cumings (1908, p. 945), Parks and Dyer (1922, p. 41) and Ruedemann (1925b, p. 134) have described the figured specimens of *Z. cincinnatiensis,* which I have not found in the central Appalachian Upper Ordovician strata. *Z. cincinnatiensis* appears to be a distinct species, although figures identified as *Z. cincinnatiensis* by Hall and Clarke (1895, pl. 54) and Foerste (1910, pl. 6) closely resemble *Z. modesta.*

Zygospira kentuckiensis, initially described by James (1878) from the Upper Ordovician of Kentucky, was thought to resemble closely *Z. modesta,* differing mostly by its larger size. Subsequent descriptions and figures of *Z. kentuckiensis* show a much closer resemblance to *Z. recurvirostra,* though *Z. kentuckiensis* is normally one and a half times larger than *Z. recurvirostra* (Foerste, 1924, p. 127). Some central Appalachian Upper Ordovician specimens which are as large as previously described Z.

kentuckiensis show no external morphological differences from the smaller *Z. recurvirostra* with which they are found.

Zygospira recurvirostra is found abundantly only in southwestern Virginia and northern Tennessee, brachiopod faunal province III (Fig. 14), in rock types varying from lime muds to muddy silts. But *Z. recurvirostra* is more characteristic of the finer grade substratum and is found with three distinct but intergrading local faunas which are all part of the Spiriferid Population of the *Zygospira–Hebertella* Community (Table 17).

TABLE 17. The associated faunal elements of *Zygospira recurvirostra* in northern Tennessee and southwestern Virginia. All species are part of the Spiriferid Population of the *Zygospira–Hebertella* Community.

	Lone Mt., Clinch Mt., Tenn.	Clinch Mt., Tenn. Powell Mt., Va. Cumberland Mt., Va.	Powell Mt., Clinch Mt., Va.
Locality numbers	125, 126, 127	131, 141, 133, 135	139, 145, 147, 149
Associated faunal elements	*Murchisonia*?	*Pterinea* (*Caritodens*) *demissa*	*Hebertella sinuata*
	Hallopora	*Ambonychia cultrata*	*Pterinea* (*Caritodens*) *demissa*
	Batostomella	*Modiolopsis modiolaris*	
Substratum	lime mud	muddy silt–silt	muddy silt–silt

The life habits and environmental setting of *Z. recurvirostra* are at least as indefinite as those of the species of strophomenids and orthids. Probably occupying a normal marine environment, *Z. recurvirostra* lived on a variety of substrata, apparently preferring muds, and was supported by a functional pedicle. Distribution could have been controlled by water turbulence and by sediment influx. The orthid *Hebertella sinuata* noticeably begins to outnumber *Z. recurvirostra* in the fine sands and silts of southwestern Virginia. Thus, *Z. recurvirostra* appears to prefer a quiet water, shelf environment, probably outer sublittoral, though it may have also occupied an inner sublittoral environment in the southern part of its distribution, where there was little terrigenous influx.

GASTROPODA

Plates 16-19

Gastropods constitute a numerically important and widespread faunal element throughout the central Appalachian Upper Ordovician strata. Bellerophontacean, pleurotomariacean and murchisoniacean gastropods are most abundant, but the small amount of well-preserved material and the lack of recent studies of the Lower Paleozoic gastropods have permitted only tentative identification of much of the Appalachian material. Dr. Ellis Yochelson of the U. S. Geological Survey has provided invaluable guidance in the taxonomic assignment of these specimens.

Ulrich and Scofield (1897) have presented the only systematic review of the North American Lower Paleozoic Gastropoda. There has been little attempt to revise their systematics, although Foerste (1914a, 1924), Ruedemann (1926), Secrist and Evitt (1943) and Wilson (1951) have made valuable contributions.

Phylum MOLLUSCA
Class GASTROPODA
Order ARCHAEOGASTROPODA
Suborder BELLEROPHONTINA
Superfamily BELLEROPHONTACEA
Family BELLEROPHONTIDAE
Subfamily PLECTONOTINAE
Genus *PLECTONOTUS*

Plectonotus? sp.

Plate 17, figures 1-9

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of small size (median diameter through the coil of 184 specimens, 6 mm; median width of 112 specimens, 3 mm), bilaterally symmetrical. Whorl profile trilobate, preserved as internal mold (Pl. 16, figs. 4, 5); median lobe prominent, arched or sharply convex; lateral lobes narrow, rounded. Aperture unknown. Umbilical sutures sharply defined, prominent shoulder above each umbilicus. Spiral band at whorl periphery preserved on latex impression of external mold, broad, raised, flat (Pl. 16, fig. 3); lunulae unknown. Surface sculpture growth lines fine, paired, intersection with spiral band sharp, swept backwards. All internal features unknown. Shell mineralogy and microstructure unknown.

Materials. The description is based on over 500 specimens from south-central Pennsylvania to west-central Virginia deposited in the Peabody Museum.

Discussion. Assignment of these central Appalachian specimens to *Plectonotus* sp. is tentative. Preservation as internal molds is most common; only one latex impression of an external mold was obtained (Pl. 16, fig. 3). A knowledge of the external characteristics is extremely important in the classification of bellerophontacean gastropods as well as of all other Archaeogastropoda. The single most important criterion for identification of the Bellerophontidae is the presence of an exhalant channel slit that generates a sweeping of growth lines, forming a peripheral spiral band called a selenizone. Boucot and Saul (1963) have reviewed the criteria for identification of a selenizone. The central Appalachian specimens exhibit this sweeping of growth lines which seems to indicate a fairly strong re-entrant angle along with a "U"-shaped sinus. The slit appears to have been narrow, but its length is unknown.

Although there are no living Bellerophontacea, Recent anatomical analogues can be found in the Pleurotomariacea (Yonge, 1947). The re-entrant notch or slit in the outer lip directs exhalant water currents passing out of the mantle cavity and is expressed in the soft anatomy by the presence of two subequal, bipectinate aspidobranch ctenidia. This fact, extrapolated into the fossil record, makes the presence or absence of the slit and the depth of the re-entrant a critical taxonomic character.

Knight, Batten and Yochelson (1960, p. I175) considered *Plectonotus* Clarke a subgenus of the sinuitid genus *Bucanella*. Figured and described by Knight (1941, p. 255–256), *Bucanella* is a trilobate bellerophontacean, characterized by a well-developed sinus but lacking a slit. Clarke (1899), in his original designation of the genus *Plectonotus,* suspected that his material had both sinus and slit; the probable slit-bearing selenizone was so poorly preserved that the later authors decided to make

Plectonotus a subgenus of the non-slit-bearing, but superficially trilobate, *Bucanella*. Recent findings by Boucot and Saul (1963, p. 1046–1047) and Boucot and Yochelson (1966, p. A7–A8) have uncovered a definite slit-bearing, trilobate bellerophontacean gastropod which they have assigned to the genus *Plectonotus*, at the same time removing it from the Sinuitidae and placing it in the Bellerophontidae.

However, as redefined by Boucot and Yochelson (1966, p. A7), *Plectonotus* is confined to beds of Early to Middle Devonian age. The genus shows some affinities to Ordovician and Silurian trilobate bellerophontacean forms, but these earlier genera are poorly understood. It is possible that many of the Silurian specimens referred to *Bellerophon trilobatus* Sowerby [see also *Sinuites* (= *Bellerophon*) *globularis* Miller and Faber 1894, p. 28, pl. 1, figs. 21, 22] are slit-bearing plectonotid-like forms. In fact, that they show a cross-section characterized by a high median lobe much like that of these central Appalachian Upper Ordovician specimens. No presently defined Ordovician bellerophontid with a slit resembles this central Appalachian form; therefore, it is possible that further study will allow an extension downward of the range of the Lower Devonian (?Silurian) genus *Plectonotus* or the introduction of an earlier slit-bearing genus into the subfamily Plectonotinae Boucot and Yochelson, 1966.

The central Appalachian Upper Ordovician *Plectonotus*? sp. is abundant in West Virginia and south-central Pennsylvania. Figure 16 shows the bellerophontaceans to be common only along the western edge of the Reedsville exposures, gastropod faunal province II; *Plectonotus*? sp. is the most numerous representative of this superfamily. The associated faunal elements are *Tancrediopsis cuneata* and *Lingula*? with lesser numbers of *Ischyrodonta truncata*, all part of the Linguloid Population of the *Orthorhynchula–Ambonychia* Community. The enclosing sediment is a muddy silt to fine sand, usually with a high organic content. Phosphate grains, many of which are thought to be partial internal fillings of the *Plectonotus*? sp. shells, are common at some locales. The sediment is often so thoroughly reworked that there are only remnant laminae (Pl. 1).

SUBFAMILY BUCANIINAE

GENUS *BUCANIA*

Bucania sp.

Plate 16, figures 10-11; plate 17, figures 1-3

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of medium to large size (median diameter through the coil of 17 specimens, 14 mm; median width of 8 specimens, 9 mm), bilaterally symmetrical. Whorl profile rounded, broadly arched. Aperture expanded, slightly wide. Umbilicus widely open. Spiral band at whorl periphery faint, preserved as internal mold, bordered by thin flanges (Pl. 17, fig. 1); lunulae unknown. Surface sculpture growth lines very faint, striae normal to anterior margin unknown. All internal features unknown. Shell mineralogy and microstructure unknown.

MATERIALS. The description is based on about 30 specimens from south-central Pennsylvania and West Virginia deposited in the Peabody Museum.

DISCUSSION. The assignment of these Upper Ordovician specimens to *Bucania* sp. was made with the aid of plates and descriptions given by Knight (1941), Reed (1920), Wilson (1951) and Ulrich and Scofield (1897). The poor preservation of the central Appalachian material and the lack of Recent Lower Paleozoic gastropod studies allows only a tentative assignment (see *Bellerophon cincinnatiensis* Miller and Faber, 1894, p. 29, pl. 1, figs. 23, 24).

Knight, Batten and Yochelson (1960, p. I180) noted that of all the slit-bearing bellerophontid genera, only *Tetranota* shows a superficial resemblance to *Bucania*. *Tetranota* is rare in the central Appalachian Upper Ordovician rocks and has been positively indentified at only one locality in northern Tennessee (loc. 133). *Bucania* sp. is common only in south-central Pennsylvania and is rare in West Virginia and west-central Virginia, gastropod faunal province II and part of I (see Table 3 for localities and Fig. 16).

Bucania sp., although geographically localized, is not everywhere associated with the same faunal elements. In contrast to the more numerous *Plectonotus*? sp., the only other common bellerophontid, it is not limited exclusively to the western parts of the Reedsville exposures, but occurs across the entire width of the Valley and Ridge Province in south-central Pennsylvania. The wider-ranging *Bucania* sp. occurs more frequently, however, with the Linguloid Population than with the Rhynchonellid and Strophomenid Populations (Table 18).

TABLE 18. The associated faunal elements of *Bucania* sp. in south-central Pennsylvania and northern Virginia.

Population	Linguloid Population of the *Orthorhynchula-Ambonychia* Community	Rhynchonellid Population of the *Orthorhynchula-Ambonychia* Community	Strophomenid Population of the *Sowerbyella-Onniella* Community
Associated faunal elements	*Plectonotus*? sp. *Tancrediopsis cuneata* *Lingula*? *Ischyrodonta truncata*	*Orthorhynchula linneyi* *Modiolopsis modiolaris* *Maclurites*? *Trochonema*	crinoid *Onniella multisecta* *Sowerbyella* (*Sowerbyella*) *sericea* *Loxoplocus* (*Lophospira*) *abbreviata* *Sinuopea*?

The geographic distribution of *Bucania* sp. is believed to be primarily limited by the availability of food and by substratum firmness. *Bucania* sp. is abundant only where the sediment is composed of a fine sand or silt, and the genus is extremely rare to the south where muds begin to constitute a greater percentage of the sediment. The substratum had to be hard or firm and the bottom waters only slightly turbid in order to allow for the proper functioning of the aspidobranch gill.

The one characteristic that distinguishes *Bucania* sp. from *Plectonotus*? sp. is its larger size. *Plectonotus*? sp. appears to have been small enough to have lived and browsed on algae, but the larger *Bucania* sp. may have been too large and heavy to be permanently supported by the algal fronds, unless it existed on that part of the frond which was continually submerged. If this was not the case or if the buoyant effect of the water was not able to offset its weight, *Bucania* sp. may have had to rely more on plant detritus accumulating on the surface of the substratum. Clumping of the plant detritus is likely and thus may explain in part the characteristic patchy distribution of *Bucania* sp., even at localities where it is most numerous.

SUBORDER PLEUROTOMARIINA
SUPERFAMILY PLEUROTOMARIACEA
FAMILY LOPHOSPIRIDAE
SUBFAMILY RUEDEMANNIINAE
GENUS *RUEDEMANNIA*

Ruedemannia? *lirata* (Ulrich and Scofield, 1897)
Plate 18, figures 1-2

[?]*Murchisonia uniangulata* var. *abbreviata* Hall, 1847, p. 304, pl. 83, figs. 2a, 2c; [?]2b, 2d.

[?]*Pleurotomaria semele* Hall 1861, p. 36.

Lophospira (?*Seelya*) *lirata* Ulrich and Scofield, 1897, p. 988, pl. 72, figs. 56, 59.

Lophospira (?*Seelya*) *lirata* var. *obsoleta* Ulrich and Scofield, 1897, p. 989, pl. 72, figs. 58; [?]57.

[?]*Plethospira semele* (Hall). Ulrich and Scofield, 1897, p. 1010, pl. 70, figs. 8, 9; [?]10.

[?]*Ruedemannia abbreviata* (Hall). Foerste, 1914a, p. 311.

Ruedemannia lirata (Ulrich and Scofield). Foerste, 1914a, p. 312. Knight, 1941, p. 303, pl. 33, figs. 3a, 3b. Knight, Batten and Yochelson, 1960, p. 1209, fig. 121.1.

Lophospira (*Ruedemannia*) *lirata* (Ulrich and Scofield). Bassler, 1919, p. 295, pl. 55, figs. 5, 6.

[?]*Lophospira lirata* (Ulrich and Scofield). Ruedemann, 1926, p. 67.

[?]*Plethospira quadricarinata* Ruedemann, 1926, p. 71, pl. 9, figs. 2, 5; [?]3, 4.

[not]*Lophospira abbreviata* (Hall). Ruedemann, 1926, p. 65, pl. 8, fig. 12; [?]11, 13.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of medium size (height of two specimens, 10 mm and 17 mm), turbiniform. Whorl profile slope about 30 degrees from vertical; whorl surface broadly rounded, two spiral threads; one thread on upper surface raised, rounded, midway between suture and whorl periphery, surface above thread steeply inclined to vertical, concave; another thread below whorl profile, less prominent. Aperture unknown. Umbilicus unknown. Sutures prominent. Spiral bands at whorl periphery rounded, usually three; outline of selenizone prominent, wide, slightly concave; U-shaped sinus broad. Surface sculpture growth lines fine, closely spaced, swept strongly backwards, almost tangential with outer spiral bands; lunulae gently concave forward. All internal features unknown. Shell mineralogy and microstructure unknown.

MATERIALS. The revised description is based on about 10 well-preserved specimens from north-central Pennsylvania deposited in the Peabody Museum.

DISCUSSION. The assignment of these central Appalachian Upper Ordovician specimens to the genus *Ruedemannia* is tentative. Foerste (1914a, p. 312) formally designated *Lophospira lirata* Ulrich and Scofield, 1897, as the type of the new genus *Ruedemannia*, which was characterized by subrotund whorls and a trilineate and bilineate peripheral band. Ulrich, however, had figured both trilineate and bilineate *L. lirata* (Ulrich and Scofield, 1897, pl. 72). Foerste (1924, p. 211) subsequently revised his definition of *Ruedemannia* to include those rotund *Lophospira* forms that Ulrich had placed in his *L. robusta* group (Ulrich and Scofield, 1897, p. 963). But Foerste expressed uncertainty that *R. lirata* was part of the *L. robusta* group. The term *Ruedemannia* was discarded by Ruedemann (1926, p. 67) in favor of *Lophospira.*

Knight (1941, p. 87) thought that *L. robusta* and *L. lirata* were congeneric and included both in the genus *Ruedemannia.* Knight (1941, p. 303) and Knight, Batten and Yochelson (1960, p. I207–209) again defined the genus *Ruedemannia* and seemed to place the major emphasis on the presence of a "U"-shaped sinus and a well-defined slit, whereas they described *Loxoplocus* (*Lophospira*) as having a "V"-shaped sinus and only a short notch, if a notch be present at all. As in the bellerophontacean gastropods, the character of the slit reflects taxonomically important differences. The rotund whorl profile also appears to be in direct contrast to the more angular profile of *Loxoplocus* (*Lophospira*). Yochelson (personal communication), however, believes that the genus *Ruedemannia* must be placed in the category of *nomen inquirendum*; the quality and amount of material studied and the lack of recent taxonomic studies do not permit the genus to be clearly distinguished from *Loxoplocus* (*Lophospira*).

Thus I have used the term *Ruedemannia*? *lirata* for rotund central Appalachian Upper Ordovician pleurotomariacean gastropods that show either a definite slit-bearing selenizone or a trilineate medial banding pattern. It may be that Ulrich's *L. robusta* group, characterized by shells with short rotund whorls, distinctly trilineate medial bands, growth lines and lunulae indicating a wide sinus and slit, is Foerste's *Ruedemannia,* but all attempts that I have made to construct even a tentative listing of species that may possibly be assigned to this genus have been unsuccessful. I have interpreted the trilineate banding pattern on the more rotund forms as some indication of a definite slit-bearing selenizone, but the value of this trilineate band as a generic character is unknown. Misidentification of these Upper Ordovician specimens as *Plethospira* or *Seelya* (Pl. 17, fig. 4) could result because the central Appalachian material shows little or no preservation of the aperture or columellar lip, but *Plethospira* and *Seelya* do not exhibit the characteristic spiral threads mid-way between the whorl periphery and sutures typical of *Ruedemannia* and *Loxoplocus* (*Lophospira*).

Ruedemannia? *lirata* is found only in north-central Pennsylvania, gastropod faunal province I (loc. 34-A, 50) at the northern limits of the pleurotomariacean distribution (Fig. 16). It is never a dominant faunal element but is locally common. The associated faunal elements are crinoids, *Hallopora* and *Ctenodonta*? *pulchella*, part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. Bassler (1919, p. 296) noted fragments of *L.* (*Ruedemannia*) *lirata* in the sandstone debris of the upper part of the Martinsburg Formation in Washington County, Maryland. I was unable to confirm this find, although my locality 124, in the same area, did produce characteristically abundant crinoids and trepostomatous bryozoans.

The substratum is composed of muddy silts, never reworked, finely laminated although occasionally showing shale pebble fragments. An inner or outer sublittoral, quiet water environmental setting appears to be indicated by the associated fauna, substratum type, geographic and stratigraphic position. *R.*? *lirata*, like all other Pleurotomariacea, probably required a firm substratum, non-turbid waters, and fed on macrophagous plant detritus.

Only one other gastropod occupies the northernmost portions of the Reedsville exposures, and less than ten specimens were found, all of which occur within gastropod faunal province I (Fig. 16). It is *Cyclonema* (loc. 75; Pl. 17, fig. 5), a platyceratacean with life habits probably quite distinct from those of *R.*? *lirata*, although these two species occasionally are associated with similar faunal elements; *Cyclonema* normally is found with crinoids, *Lyrodesma poststriatum*, *Ambonychia radiata* and *Rafinesquina* "*alternata*", part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. It is thought that the Upper Ordovician *Cyclonema*, like the Devonian species of *Cyclonema*, may have been coprophagous commensals on crinoids (Bowsher, 1955).

SUBFAMILY LOPHOSPIRINAE

GENUS *LOXOPLOCUS*

Loxoplocus (*Lophospira*) *abbreviata* (Hall, 1847)

Plate 18, figures 4-6

Murchisonia uniangulata var. *abbreviata* Hall, 1847, p. 304, pl. 83, fig. 2d; [?]2a, 2b, 2c.

[?]*Schizolopha moorei* Ulrich (*in* Ulrich and Scofield), 1897, p. 992, pl. 65, figs. 31-37.

Lophospira uniangulata var. *abbreviata* (Hall). Whitfield and Hovey, 1898, p. 52.

[?]*Ruedemannia abbreviata* (Hall). Foerste, 1914a, p. 311.

Lophospira abbreviata (Hall). Ruedemann, 1926, p. 65, pl. 8, figs. 11, 13, [?]12.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of small size (median height of 12 specimens, 7 mm), conispiral, high spired. Whorl profile slope about 25 degrees from vertical; whorl surface broadly rounded, slight angulation near suture, no pronounced spiral threads. Aperture unknown. Umbilicus unknown. Sutures sharp, deep. Spiral band at whorl periphery raised, angular; lunulae unknown. Surface sculpture fine, faintly preserved as external molds, intersection with peripheral spiral band broadly angular, not sharp or swept backwards. All internal features unknown. Shell mineralogy and microstructure unknown.

MATERIALS. The description is based on about 40 specimens from north-central Pennsylvania and northern Virginia deposited in the Peabody Museum.

DISCUSSION. The assignment of these central Appalachian Upper Ordovician specimens to *Loxoplocus* (*Lophospira*) *abbreviata* is tentative. A problem of assignment arises from the subsequent designation of lectotypes by Foerste (1914a) and Ruedemann (1926) from Hall's *Murchisonia uniangulata* var. *abbreviata* material (1847, pl. 83, figs. 2a-2d). Foerste (1914a, p. 311), reworking Hall's material, formally designated Hall's figure 2c as the lectotype of the species *Ruedemannia abbreviata*. His main criterion was that this figure showed the best developed trilineate peripheral bands and an overall sub-rotund whorl profile. However, later Foerste (1924, p. 211) failed to mention *R. abbreviata* in his vague re-definition of the genus *Ruedemannia*. The generic problems are further reviewed under the discussion of *R.*? *lirata* (see p. 104).

Ruedemann (1926), working in western New York, uncovered abundant specimens from the upper part of the Whetstone Gulf and lower Pulaski Formations, possibly topotypic with Hall's *Murchisonia uniangulata* var. *abbreviata,* and designated them as *Lophospira abbreviata*. Ruedemann (1926, p. 66–67) disregarded the term *Ruedemannia* and Foerste's formal designation of Hall's figure 2c (1847, pl. 83) as the type and instead informally designated figures 2a or 2b as the lectotype(s) of the species *L. abbreviata,* failed to mention figure 2c, and claimed that figure 2d "probably does not belong here".

It is certainly possible that Hall's syntypes do contain two distinct taxa. Hall's figure 2c appears more closely related to *R.*? *lirata*, and, in fact, Ruedemann's figure 12 (1926, pl. 8), a fragment of an apparently non-related exterior, showing a definite selenizone with broadly concave lunulae and growth lines sweeping well back along the flanges of the selenizone, also resembles *R.*? *lirata*. The central Appalachian Upper Ordovician specimens correspond more closely to Hall's figure 2d (1847, pl. 83) and Ruedemann's figures 11 and 13 (1926, pl. 8). They appear to be non-slit-bearing forms and, although broadly rounded, they do not resemble *R.*? *lirata*. *L.* (*L.*) *abbreviata* must be classified as *nomen inquirendum* pending a complete taxonomic review of this material.

Loxoplocus (*Lophospira*) *abbreviata* is common at localities in south-central Pennsylvania (see Table 3, loc. 101, 106, 107) and in central Virginia (loc. 167, 169, 172; see Fig. 16) always along the eastern edge of the Reedsville exposures, gastropod faunal province I. Rare specimens of *L.* (*L.*) *abbreviata* have also been identified to the south and west of these exposures (see loc. 87, 97, 147, 148, 152, 203). The associated faunal elements usually found with *L.* (*L.*) *abbreviata* are *L.* (*L.*) *ventricosta, L.* (*L.*) *perangulata, Sinuopea*? and lesser numbers of *R.* "*alternata*", *O. linneyi* and *Modiolopsis modiolaris,* which are generally considered part of the *Sowerbyella–Onniella* Community, but rock samples include occasional species more characteristic of the Rhynchonellid Population of the *Orthorhynchula–Ambonychia* Community. I have found that specimens of *L.* (*L.*) *abbreviata* are also commonly clumped together. Ruedemann (1926, p. 66) identified *L.* (*L.*) *abbreviata* at only three localities in western New York. He considered it a rare Lorraine fossil, but occasionally very abundant locally near the contact between the Whetstone Gulf Shale and the Pulaski Formation.

The probable environmental setting of *L.* (*L.*) *abbreviata* can only be inferred from the ecology of Recent pleurotomariacean gastropods. Pleurotomariacean anatomy has been studied in detail by Yonge (1947), and in the process he has gathered a small but valuable amount of ecological data. Because these Archaeogastropoda have simple aspidobranch, bipectinate ctenidia, the animal has difficulty in freeing mud-size particles from the gill filaments. The gill structure dictates life on a firm substratum where there is little turbid water. Pleurotomariaceans are commonly macrophagous herbivores that browse on algae or move along the substratum ingesting detrital plant material (Graham, 1955, p. 149). Batten (1958, p. 169) noted that Recent Pleurotomariacea live between 50 and 200 fathoms and seem better adapted to colder, possibly deeper waters, though some can tolerate brackish water conditions.

The Upper Ordovician Pleurotomariacea are not widespread but probably occupied an inner sublittoral, quiet water environment. One of the factors controlling the distribution was probably substratum type, which, in the central Appalachians, is usually a fine, possibly firm silt or sand. The patchiness and local clumping of this gastropod may be associated with the probable irregular distribution of detrital plant material by currents moving over the substratum. The influence of water temperature and salinity is difficult to ascertain for any of the Upper Ordovician pleurotomariacean species.

Loxoplocus (*Lophospira*) *ventricosta* (Hall, 1847)

Plate 18, figure 3

Murchisonia ventricosta Hall, 1847, p. 41, pl. 10, fig. 3. Emmons, 1855, p. 162. [not] Salter, 1859, p. 23, pl. 5, figs. 2, 2a, 3.

[?]*Lophospira peracuta* Ulrich and Scofield, 1897, p. 976, pl. 73, figs. 15-17. Wilson, 1951, p. 36, pl. 3, fig. 4.

Lophospira ventricosta (Hall). Bassler, 1915, p. 766. Wilson, 1951, p. 39, pl. 4, figs. 23, [?]22.

[?]*Lophospira manitoulinensis* Foerste, 1924, p. 213, pl. 36, figs. 5a-d.

[?]*Lophospira liosutura* Secrist and Evitt, 1943, p. 366, fig. 12.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of medium size (height of one specimen, 18 mm; diameter of last whorl, 13 mm), conispiral, high-spired. Whorl profile slope about 25 degrees from the vertical; whorl upper surface sharply convex, angular, lower surface gently convex, spiral threads absent. Aperture unknown. Sutures prominent, shallow. Spiral band at whorl periphery raised, angular; lunulae unknown. Surface sculpture unknown. All internal features unknown. Shell mineralogy and microstructure unknown.

MATERIALS. The description is based on 10 partial specimens from north-central Virginia deposited in the Peabody Museum.

DISCUSSION. Assignment of these central Appalachian Upper Ordovician specimens to *Loxoplocus* (*Lophospira*) *ventricosta* is tentative. The specimens show a prominent, raised peripheral band, a sharply convex, non-threaded upper whorl surface and pronounced sutures, all of which are characteristic of numerous Lower Paleozoic *Lophospira* species, Hall (1847, p. 41) introduced the term *Murchisonia ventricosta* for some New York specimens; this appears to be the earliest description of a North American species similar to these central Appalachian forms. Wilson (1951, p. 39) remarked that Hall's illustration of the holotype (1847, pl. 10, fig. 3) is inadequate. She figures two specimens (1951, pl. 4, figs. 22, 23) from the Ottawa area identified by Billings as *Murchisonia ventricosta*, but only tentatively assigns them to the species. *L.* (*L.*) *ventricosta* must be classified as *nomen inquirendum*.

Abundant *L.* (*L.*) *ventricosta* occur in north-central Virginia, gastropod faunal province I (Table 3, loc. 167, also Fig. 17). This is the type locality of Secrist and Evitt's *Lophospira liosutura* (1943, p. 366, fig. 12), which may be conspecific with *L.* (*L.*) *ventricosta*. Dr. Ellis Yochelson kindly made available Secrist and Evitt's type material deposited in the U.S. National Museum. We have tentatively identified their figured specimens of *Lophospira liosutura* as occurring in a porous sandstone block labeled "25.6 feet". The label probably refers to Secrist and Evitt's "80 foot horizon" of the Passage Creek section (1943, p. 362), which they state is a six-inch porous bed in which *Lophospira* is very abundant. I have re-collected from this bed which has produced abundant specimens of Sinuopeidae, some *Seelya* (Pl. 17, fig. 4) and the *L.* (*L.*) *ventricosta* (?= *Lophospira liosutura*). A re-collection and more careful restudy of the gastropods along the eastern edge of the Reedsville exposures in south-central Pennsylvania and northern Virginia where the pleurotomariacean gastropods are most common may show *L.* (*L.*) *ventricosta* to be somewhat more widely distributed, but remaining within this restricted area of the central Appalachians. *L.* (*L.*) *ventricosta* presumably lived in much the same manner as *L.* (*L.*) *abbreviata*; that is, in a quiet water, shallow sublittoral environment.

Loxoplocus (*Lophospira*) *perangulata* (Hall, 1847)
Plate 18, figures 4 and 7

Murchisonia perangulata Hall, 1847, p. 41, pl. 10, fig. 4.
Murchisonia perangulata var. A. Hall, 1847, p. 179, pl. 38, figs. 7a, 7b.
Murchisonia bicincta var. *perangulata* (Hall). Salter, 1859, p. 19, pl. 4, fig. 7.
Lophospira perangulata (Hall). Ulrich and Scofield, 1897, p. 972, pl. 73, figs. 1-3, 5-7, [?]4. Ruedemann, 1901, p. 31. Bassler, 1909, pl. 3, figs. 9-13. Wilson, 1951, p. 37, pl. 4, fig. 13.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of small size (median height of four specimens, 7 mm), conispiral, fusiform. Whorl profile slope about 20 degrees from the vertical; whorl surface broadly rounded, no pronounced spiral threads. Aperture unknown. Umbilicus unknown. Sutures prominent. Spiral band at whorl periphery raised, rounded, preserved as internal mold, lunulae unknown. Surface sculpture unknown. All internal features unknown. Shell mineralogy and microstructure unknown.

MATERIALS. The description is based on about 10 mostly fragmentary specimens from central Virginia deposited in the Peabody Museum.

DISCUSSION. The assignment of these specimens to *Loxoplocus* (*Lophospira*) *perangulata* is tentative. Hall (1847, p. 41, 179) introduced the terms *Murchisonia perangulata* for specimens found in the New York Birdseye (Lowville) Limestone, and *M. perangulata* var. A for specimens in the New York Trenton Limestone. Hall believed the Trenton variety closely resembled *M. bicincta*, with which it occurred; but he felt that further study would show it to be similar to the Birdseye *M. perangulata.*

Salter (1859, p. 19) informally placed Hall's Birdseye *M. perangulata* in synonymy with *M. bicincta*, stating that it did not differ significantly from small *M. bicincta.* Salter figured one specimen called *M. bicincta* var. *perangulata* (1859, pl. 4, fig. 7), apparently as a representative juvenile form of *M. bicincta.* The New York Trenton Limestone *M. perangulata* var. A was considered by Salter a distinct, more elongate species.

Ulrich's subsequent designation of the type *Lophospira perangulata* (in Ulrich and Scofield, 1897, p. 972) was specifically restricted to Hall's *M. perangulata.* Ulrich also considered Hall's *M. perangulata* var. A a separate species, but he designated no specific assignment and presented no synonymy. Ruedemann (1901, p. 31), working in the Trenton conglomerate of eastern New York, described specimens which he felt came nearer to Hall's Birdseye *M. perangulata* than his Trenton *M. perangulata* var. A; therefore, he justified the use of the term *Lophospira perangulata* after Ulrich.

The specimens I have collected from the central Appalachian Upper Ordovician appear in closer agreement with Hall's Trenton *M. perangulata* var. A, but I have used the term L. (*L.*) *perangulata* realizing that a complete revision of this taxon is required. The following list may contain some junior subjective synonyms:

Loxoplocus (*Lophospira*) *milleri* [= L. (*L.*) *bicincta* (Miller)]
L. (*L.*) *medialis* (Ulrich and Scofield)
L. (*L.*) *perangulata* (Hall)
L. (*L.*) *perangulata* var. A (Hall)
L. (*L.*) *helicteres* (Salter)

Abundant specimens of L. (*L.*) *perangulata* occur in central Virginia (loc. 174, 177, 179), along the eastern edge of the Reedsville exposures. Specimens are rarely found outside this area. The commonly associated abundant faunal elements are *Lingula*?, *Bucania* sp., *Ischyrodonta*? *truncata* and L. (*L.*) *abbreviata*. The substratum is a fine silt and the most probable environmental setting is a quiet water, inner sublittoral environment. The common pattern of clustering is observed as in the other gastropods and again could be associated with the availability of food on the substratum. Recent pleurotomariacean ecology is reviewed under the discussion of L. (*L.*) *abbreviata* (p. 106).

Family SINUOPEIDAE
Subfamily SINUOPEINAE

Genus *SINUOPEA*?
Plate 19, figures 1-2

The identification of these central Appalachian Upper Ordovician specimens was critically reviewed by Dr. Ellis Yochelson, who believes that these pleurotomariacean gastropods can be classified only as members of the Family Sinuopeidae and do not resemble any existing genus in that family. The central Appalachian specimens are only suggestive of the genus *Sinuopea* in their deep sutures and "U" shaped sinus, and because of the pronounced shoulder of the upper whorl surface of the central Appalachian specimens the present generic assignment is in doubt.

The sinuopeid gastropods constitute an abundant faunal element only in south-central Pennsylvania and northern Virginia, gastropod faunal province I (loc. 101, 163, 167, see Fig. 16), along the eastern edge of the Reedsville exposures. The geographic distribution is close to that of *Loxoplocus* (*Lophospira*) *abbreviata* and L. (*L.*) *ventricosta*, faunas common to the Strophomenid Population of the *Sowerbyella–Onniella* Community. Other less common associated faunal elements are *Trochonema* (Pl. 17, fig. 6), *Maclurites*?, *Bucania* sp., *Ischyrodonta truncata* and *Orthorhynchula linneyi*. A few sinuopeids are also occasionally found with *Tancrediopsis cuneata*, *Lingula*?, *Plectonotus*? sp. (loc. 84), i.e., the Linguloid Population of the *Orthorhynchula–Ambonychia* Community, and the crinoids, *Onniella multisecta* and *Sowerbyella* (*Sowerbyella*) *sericea* (loc. 107), part of the Strophomenid Population of *Sowerbyella–Onniella* Community. The two latter faunal associations are found to the west and north of the main pleurotomariacean belt in south-central Pennsylvania, gastropod faunal province I (Fig. 16).

The patchiness of the sinuopeid gastropod distribution seems to be characteristic of all Upper Ordovician pleurotomariaceans. The sinuopeid occurrences define a broadly linear north-south belt from south-central Pennsylvania to northern Virginia. The environmental setting of the pleurotomariid gastropods is reviewed under the discussion of *L.* (*L.*) *abbreviata*, p. 106. The sinuopeids are believed to have differed little from the other Pleurotomariacea in their life habits.

?Suborder MURCHISONIIA
Superfamily MURCHISONIACEA
Family MURCHISONIIDAE

Genus *MURCHISONIA*?

Plate 19, figures 3-4

The assignment of these Upper Ordovician specimens was reviewed by Dr. Ellis Yochelson, who felt that the quality of preservation permitted classification only as representative of the Family Murchisoniidae. The infrequent, but well-defined, peripheral band, the fusiform whorl profile, and the deep sutures are somewhat reminiscent of the genus *Murchisonia*, but again the generic assignment is in doubt.

The murchisoniid gastropods are found only along Clinch and Cumberland Mountains in northern Tennessee, gastropod faunal province III (loc. 130, 133, 135; see Fig. 16). The rock type is consistently a silty mud or carbonate mud, in direct contrast to the silt-fine sand substratum associated with the bellerophontid and pleurotomariid gastropods. The taxonomic diversity of the murchisoniid faunal association is notably lower than in the other two gastropods; *Zygospira recurvirostra* from the Spiriferid Population of the *Zygospira–Hebertella* Community is the only abundant associated faunal element, although a few *Pterinea* (*Caritodens*) *demissa* and large *Loxoplocus* (*Lophospira*) sp. are present with the murchisoniids.

Cox and Knight (1960, p. I290) reviewed the taxonomic status of the Superfamily Murchisoniacea and thought it could be considered an archaeogastropod, a mesogastropod, or a transitional form between the two. The submedial sinus and slit, presumably exhalant in function, point to the Pleurotomariina (Archaeogastropoda), whereas the high-spired, many-whorled nature of the murchisoniids and their tendency to develop what appears to be an inhalant channel suggests a Cerithiacea (mesogastropod) stock. The suborder Murchisoniina was erected by Cox and Knight (1960) for the reception of the Superfamily Murchisoniacea, in the belief that the murchisoniids still retain the primitive features of the Archaeogastropoda but show some characteristic evolutionary advances along the lines leading to the Mesogastropoda.

The morphologically transitional nature of the murchisoniids may be reflected in their Upper Ordovician environmental setting that places them geographically apart from the abundant Archaeogastropoda (Bellerophontacea and Pleurotomariacea). Yonge (1947, p. 495) noted that the complex bipectinate aspidobranch ctenidium of the Archaeogastropoda is easily fouled by sediment, and mud particles can be removed from the ctenidia only with difficulty. Therefore, Recent pleurotomariid gastropods as a whole can exist effectively only in clear waters and on a firm substratum. As Lower Paleozoic pleurotomariid populations probably expanded gradually into muddier substrata, those individuals possessing a ctenidial structure from which mud particles could be more easily removed would have had a selective advantage. Along with the development of the monopectinate ctenidium, evolutionary changes advantageous to the mud-dwellers would be the emergence of an extensible inhalant siphon and modification of the foot to allow the ancestral mesogastropod to move on or through a soft substratum.

BIVALVIA
Plates 20-44

The Bivalvia, next to the Brachiopoda, are the most abundant and widespread faunal element in the central Appalachian Upper Ordovician rocks. The class is represented by five superfamilies and ten common species. There are rare and scattered specimens of two additional superfamilies, Nuculanacea (*Nuculites* and *Palaeoneilo*) and Cyrtodontacea (*Cyrtodonta*?).

The taxonomy and systematics of the North American Ordovician Bivalvia have been neglected for over half a century, but recent studies of Lower Paleozoic nuculoids by McAlester (1963, 1964, 1968) and ambonychiids by Pojeta (1962, 1966) mark the beginning of renewed interest. Investigations of European species by Isberg (1934) and the excellent survey by Babin (1966) have been of considerable use in this study. Papers dealing with the Ordovician Bivalvia of eastern North America include Hall (1847), Hall and Whitfield (1875), Ulrich (1893, 1894), Bassler (1919), Stewart (1920), Foerste (1924), Ruedemann (1926) and Wilson (1956).

Phylum MOLLUSCA
Class BIVALVIA
Subclass PALAEOTAXODONTA
Order NUCULOIDA
Superfamily CTENODONTACEA
Family CTENODONTIDAE
Genus *CTENODONTA*?

Ctenodonta? *pulchella* (Hall, 1847)
Plate 20, figures 1-4

Lyrodesma pulchella Hall, 1847, p. 302, pl. 82, figs. 12a, b, d; [not]12c.
Leda pulchella (Hall). Emmons, 1855, p. 173.
Tellinomya (*Lyrodesma*) *pulchella* (Hall). Hall, 1856, p. 395. Hall, 1857c, p. 136.
Ctenodonta pulchella (Hall). Ulrich, 1894, p. 581. Foerste, 1914, p. 305. Ruedemann, 1926, p. 14.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of small size, broadly oval, equilateral (median height of five specimens, 7 mm; median length, 7 mm). Shape variation appears limited to very slight differences in height-length properties. Surface sculpture of fine concentric striae. Taxodont teeth of moderate size, decreasing in size toward the umbo; teeth continuous beneath umbo. Resilifer absent, ligament area otherwise unknown. Original shell microstructure and mineralogy unknown.

Materials. The description is based on about 20 specimens from north-central Pennsylvania deposited in the Peabody Museum.

Discussion. The assignment of these central Appalachian Upper Ordovician specimens to the genus *Ctenodonta* is tentative, pending a thorough restudy of all Upper Ordovician nuculoid bivalves. Until recently all North American Ordovician nuculoid bivalves had been assigned to the genus *Ctenodonta*, but many of these species do not appear to be congeneric with the type *Ctenodonta nasuta* (McAlester, 1963). This is true for *Ctenodonta*? *pulchella*, which I believe may merit a separate generic designation after a restudy of other North American material, and hence the present generic assignment is questioned.

Ulrich (1894, p. 581) placed *C. pulchella* in his Group IV, ctenodonts typified by *C. pectunculoides*. Group IV consisted of five species:

Ctenodonta pulchella (Hall, 1847)
C. pectunculoides (Hall, 1871)
C. cingulata (Ulrich, 1879)
C. subrotunda (Ulrich, 1892)
C. circularis Ulrich 1894

The first three appear to form an internally coherent morphological grouping, but *C. subrotunda* may be a *Palaeoconcha* Miller, 1889 and *C. circularis* is a *nomen nudum*, as the species was never described or figured. The following is my tentative listing of possible congeneric species. No evaluation of the subjective synonymies that may exist in this list is possible at the present time.

Ctenodonta pulchella (Hall, 1847)
C. pectunculoides (Hall, 1871)
C. cingulata (Ulrich, 1879)
C. lorrainensis Foerste 1941
C. borealis Foerste 1924

Ctenodonta? *pulchella* is abundant at localities 34-A, 35, and 37 in north-central Pennsylvania, bivalve faunal province I, and is very rarely found outside this area (Fig. 17). Associated faunal elements include *Praenucula levata, Lyrodesma poststriatum*, crinoids and occasionally *Hallopora, Zygospira modesta* and *Onniella multisecta*, part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community. The substratum is commonly a finely laminated silt and mud; the environmental setting appears to have been sublittoral and subjected to only moderate turbulence. By analogy with Recent nuculoid bivalves, *C.*? *pulchella* was probably an infaunal detritus feeding form, a life habit that is locally dominant in these Upper Ordovician offshore mud and silt environments.

GENUS *TANCREDIOPSIS*

Tancrediopsis cuneata (Hall, 1856)

Plate 21, figures 1-7; plate 22, figures 1-6; plate 23, figures 1-5; plate 24, figures 1-3

Tellinomya cuneata Hall, 1856, p. 392, figs. 6, 7. Hall, 1857a, p. 183, figs. 6, 7. Hall, 1857b, p. 143, figs. 6, 7. [not] Hall, 1862b, p. 38, figs. 1, 2.

Ctenodonta contracta Salter, 1859, p. 37, pl. 8, figs. 4, 5. Logan, 1863, p. 175, figs. 160a, b. Wilson, 1956, p. 23, pl. 2, figs. 7-9.

Ctenodonta (*Tancrediopsis*) *contracta* (Salter). Beushausen, 1859, p. 70.
[?]*Tellinomya contracta*? (Salter). Walcott, 1884, p. 76, pl. 11, figs. 15, 15a.
Tancrediopsis cuneata (Hall). McAlester, 1963, p. 5, figs. 1-80.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of medium size, equivalved, strongly inflated, umbones very prominent (median length of 42 specimens, 14 mm; median height, 9 mm). Shape variable, height ranging from 57 to 76 per cent of length (median of 42 measured specimens, 66 per cent). Surface sculpture of faint, widely spaced concentric striae; sculpture usually obscure because of internal mold preservation. Large, chevron-shaped taxodont teeth; about equal numbers of teeth on either side of, and pointed toward, umbo; teeth are continuous beneath umbo but decrease in size. Resilifer absent, ligament area otherwise unknown. Anterior and posterior adductor muscle scars prominent, emphasized by sharp ridge on inner side of each scar, more prominent on anterior; pedal retractor muscle scars small but prominent, located at dorsal end of the inner adductor ridges; other internal features unknown. Original shell microstructure and mineralogy unknown.

Materials. The description is based on over 200 specimens from central Pennsylvania to southeastern Virginia deposited in the Peabody Museum.

Discussion. The taxonomic status of *Tancrediopsis cuneata* was reviewed by McAlester (1963). My central Appalachian specimens can be assigned to this species and exhibit only slight morphological variation from northern to southern localities, bivalve faunal province II (Fig. 17). They remain constantly associated with the same abundant faunal elements, *Lingula*?, *Plectonotus*? sp. and occasionally *Ischyrodonta truncata*, part of the Linguloid Population of the *Orthorhynchula–Ambonychia* Community. This faunal assemblage dominates inner sublittoral and intertidal environments from central Pennsylvania into central Virginia and is apparently able to tolerate variations in substratum (muddy silts to medium sand), possibly salinity, and temperature. A more complete review of the ecological requirements of this assemblage is presented in the chapter on paleoautecology (p. 36).

Not included in this description are some questionable nuculoid bivalves from localities 135 and 148 in southwestern Virginia and Tennessee, bivalve faunal Province III (Pl. 20, figs. 9-11). They may belong to the genus *Palaeoneilo* Hall and Whitfield, 1869, although their poor preservation does not permit any positive assignment; only the notable posterior expansion gives any clue to the taxonomic placement of these specimens. They are smaller than the typical *T. cuneata* (median length of 23 specimens, 11 mm; median height, 5 mm) and are found almost to the exclusion of any other faunal elements at localities 135 and 148, but the species may be part of the *Zygospira–Hebertella* Community.

Superfamily NUCULACEA

Family PRAENUCULIDAE

Genus *PRAENUCULA*

Praenucula levata (Hall, 1847)

Plate 20, figures 5-8

Nucula levata Hall, 1847, p. 150, pl. 34, figs. 1a-d, f-i; [?]1e, k.

Leda levata (Hall). Emmons, 1855, p. 137, pl. 14, fig. 10.

Tellinomya (*Nucula*) *levata* (Hall). Hall, 1856, p. 395. Hall, 1857c, p. 136.

Ctenodonta levata (Hall). Billings, 1863, p. 175, figs. 161a, b. Ruedemann, 1912, p. 100, pl. 6, fig. 1. Wilson, 1956, p. 25, pl. 2, figs. 10-13.

Tellinomya levata (Hall). Hall, 1871, pl. 3, fig. 27. Hall, 1872, pl. 7, fig. 27. Hall and Whitfield, 1875, p. 82, pl. 1, fig. 23.

[?]*Ctenodonta filistriata* (Hall and Whitfield). Ulrich, 1894, p. 599, figs. 44a-e. Bassler, 1919, p. 297, p. 54, figs. 26-29. [?]Stewart, 1920, p. 9, pl. 1, fig. 5. Foerste, 1924, p. 134, pl. 18, figs. 7a, b. Ruedemann, 1926, p. 14, pl. 1, figs. 13, 14.

Tellinomya (*Ctenodonta*) *levata* (Hall). Clarke and Ruedemann, 1903, p. 521.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of small size, equivalved, anteriorly elongated (median length of eight specimens, 7 mm; median height, 5 mm). Shape variable, height ranging from 62 to 84 per cent of length (median of eight measured specimens, 78 per cent); distance from anterior extremity to umbo ranging between 57 and 64 per cent of length (median of six measured specimens, 62 per cent). Surface sculpture unknown, preserved only as internal molds. Prominent taxodont teeth, chevron-shaped, pointed toward umbo; teeth continuous but decreased abruptly in size under umbo; subequal in size on either side of umbo. Resilifer absent, ligament area otherwise unknown. Anterior muscle scar subround, weakly impressed; other internal features unknown. Original shell microstructure and mineralogy unknown.

MATERIALS. The description is based on about 10 specimens from central Pennsylvania deposited in the Peabody Museum.

DISCUSSION. A survey of the North American Ordovician literature reveals that some species now assigned to the genus *Ctenodonta* probably belong to the genus *Praenucula* Pfab, 1934. I have tentatively assigned my central Appalachian specimens to this genus pending taxonomic re-evaluation of other North American material.

Hall (1847, p. 150) remarked in his description of *Ctenodonta* (= *Nucula*) *levata* that the shell "presents considerable variation in form, even in the same locality." But it appears that his figures show more than one species; i.e., figures 1e and 1k (pl. 34) appear to belong to the genus *Palaeoconcha* Miller, 1889. The other figures seem to be *Praenucula*, although they show considerable variation in the degree of posterior expansion. Hall designated no type for the species *C. levata*. Wilson (1956, p. 25) also has noted that Hall's material appeared to contain more than one species, but she stated that Ulrich and Ruedemann after examination of Hall's specimens decided upon a lectotype for *C. levata*. Wilson further pointed out that the specimen chosen by Ulrich and Ruedemann was figured by Ruedemann (1912, pl. 6, fig. 1), but I have found no subsequent type designation presented by Ruedemann (see 1912, p. 110). Furthermore there is no discussion of the status of Hall's syntypes by either Ruedemann or Wilson. That plate 6, figure 1 (Ruedemann, 1912) is the subsequently designated type of *C. levata* rests on the interpretation of Wilson (1956). No authors have considered the difficulties created by the shape variation that Hall's specimens show, or faced the obvious problems of preservation that appear to have plagued Wilson (1956, p. 25). What appears to me to have been the supposed "key criterion" for the identification of *C. levata*, the slightly subangular anterodorsal projection, is rarely preserved.

McAlester (1968, p. 46) described the type species of the genus *Praenucula* (*Praenucula expansa* Pfab, 1934) as being of unknown shape variability, although showing a well-defined anterior elongation. I have listed below the North American species that may belong in this genus; there are notable differences in the degree of anterior expansion, but all appear to show subequally sized taxodont teeth on either side of the umbo.

Ctenodonta levata (Hall, 1847)
C. donaciformis (Hall, 1847)
C. abrupta Billings 1865
C. nitida (Ulrich, 1892)
C. medialis Ulrich 1894
C. scofieldi Ulrich 1894
C. retrosa Ulrich 1893 (1895)
C. filistriata Ulrich 1894
C. albertina Ulrich 1894
C. simulatrix Ulrich 1894
C. madisonensis Ulrich 1894
C. calvini Ulrich 1894
C. perminuta Ulrich 1893 (1895)
C. nuculiformis (Hall, 1847)
C. (?) *hilli* (Miller, 1874)
[?]*C. socialis* Ulrich 1894
[?]C. *fecunda* (Hall, 1862)

This group includes most of Ulrich's *C. levata* or Group III ctenodonts (1894). Excluded are:

Ctenodonta hartsvillensis Safford 1869, probably a *Palaeoconcha*
C. danvillensis Ulrich 1894, *nomen nudum*
C. tumida Ulrich 1894, *nomen nudum*
C. mundula Ulrich 1894, *nomen nudum*

Those species designated as *nomina nuda* have never been figured or described. Additions to the list of possible North American *Praenucula* include the following:

Ctenodonta planodorsata (Ulrich, 1892)
C. prosseri Ruedemann 1912
C. radiata Ruedemann 1912
C. recta Ruedemann 1912
C. myalta Stewart 1920
C. chambliensis Foerste 1924
C. hyacinthensis Foerste 1924

Praenucula levata is commonly found with *C.? pulchella, Lyrodesma poststriatum* and lesser numbers of crinoids, *Hallopora* and *Onniella multisecta*, which are part of the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community, at localities 37, 52, and 97 in central Pennsylvania, bivalve faunal province I (Fig. 17). Ruedemann (1926, p. 15) also found what appear to be species of *Praenucula* and *Ctenodonta*? commonly associated throughout the Whetstone Gulf Shale in western New York. The environmental setting for the central Appalachian species appears to be in quiet, offshore waters. The substratum is a finely laminated silt and mud which is dominated by small patches of infaunal, detritus feeding nuculoid bivalves. *P. levata* and *C.*? *pulchella* constitute the greatest number of these infaunal forms, although there are scattered specimens of *Nuculites* and *Palaeoconcha.*

Subclass PTERIOMORPHIA
Order PTERIOIDA
Suborder PTERIINA
Superfamily AMBONYCHIACEA
Family AMBONYCHIIDAE
Genus *AMBONYCHIA*

Ambonychia radiata Hall 1847

Plate 36, figures 1-6

Pterinea carinata Emmons, 1842, p. 204, fig. 111.1. Vanuxem, 1842, p. 64, fig. 9.1. Owen, 1844, p. 376. Emmons, 1855, p. 175, pl. 17, fig. 23.

Ambonychia radiata Hall, 1847, p. 292, pl. 80, figs. 4a, b, c, f, [not]figs. 4d, h-l. Hall, 1859a, p. 8; p. 110, figs. 1, 2. Hall, 1859b, p. 269; p. 523, figs. 1, 2. Hall, 1862b, p. 54, figs. 11.1, 11.2. [not]Billings, 1863, p. 215, fig. 219. Hall and Whitfield, 1875, p. 79, pl. 2, fig. 2. Stoliczka, 1870, p. XXI. Stoliczka, 1871, p. 387.

Ambonychia carinata (Emmons). Lesley, 1889, p. 22, fig. 111.b.

Byssonychia radiata (Hall). Ulrich, 1893 (1895), p. 629. Foerste 1914a, p. 273, pl. 3, figs. 12A-C. Bassler, 1919, p. 282, pl. 57, fig. 26. Stewart, 1920, p. 23, pl. 4, fig. 3. Foerste, 1924, p. 164, pl. 27, figs. 3a, b; pl. 31, figs. 13a, b, c. Ruedemann, 1926, p. 27, pl. 3, figs. 4-7. [not]Butts, 1941, p. 127, pl. 100, figs. 6-8. [not]Wilson, 1948, p. 144, pl. 18, fig. 16. Pojeta, 1962, p. 183, pl. 22, figs. 1-15; pl. 23, figs. 1-14; pl. 24, figs. 1-7.

Byssonychia vera Ulrich, 1893 (1895), p. 629, figs. a-c. Bassler, 1919, p. 282, pl. 54, figs. 34-36. Stewart, 1920, p. 25, pl. 1, figs. 23, 24. [not]Butts, 1941, p. 127, pl. 100, fig. 9.

Byssonychia bowmani Secrist and Evitt, 1943, p. 363, figs. 4, 5.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of small to medium size, moderately inflated, equivalved, rounded posterior expansion (median diagonal of six specimens, 24 mm; median length, 20 mm). Shape only slightly variable, length varying between 82 and 85 per cent of the diagonal. Byssal gap prominent, elliptical, small; byssal sinus moderate. Anterior margin rounded; umbones rounded. Surface sculpture of radial ribs, about 50; faint concentric striae. Small cardinal teeth, one or two, radiating from beneath umbo; posterior lateral teeth, two or three, elongate. Ligament longitudinally striated, ligament area otherwise unknown. Posterior adductor large, subround; other internal features unknown. Original shell microstructure and mineralogy unknown.

Materials. The description is based on over 15 specimens from central Pennsylvania deposited in the Peabody Museum.

Discussion. Pojeta (1962, p. 183; 1966, p. 172) discussed in detail the taxonomic status of this species, the type of the genus *Ambonychia*. The Upper Ordovician Appalachian specimens that I have assigned to this species are abundant at some locales (loc. 72, 78), and are confined geographically to central Pennsylvania, bivalve faunal province I. Localities farther south produce some questionable *A. radiata* fragments, though the ribbing appears to resemble *A. ulrichi* (esp. loc. 127). I recollected from Secrist and Evitt's (1943) type locality of *Byssonychia bowmani* (my locality 167) and found most specimens indistinguishable from *A. radiata*; there were a few specimens that appear similar to *A. praecursa* but are too poorly preserved for an accurate identification.

Almost all of the North American literature seems to emphasize the importance of *A. radiata* as the characteristic *Ambonychia* in the central Appalachians, but this is certainly not the case, as *A. praecursa* is far superior in numbers. I believe that the misidentification of *A. praecursa* as *A. radiata* has accounted for much of the discrepancy. The variability of shell shape recorded by me must be viewed cautiously because there are few whole *A. radiata* in the central Appalachian collection. My central Appalachian *A. radiata* are, however, slightly smaller and more rounded than are most previously figured specimens.

A tentative listing of possible subjective synonyms of *A. radiata* includes the following:

Ambonychia obesa (Ulrich, 1893)
A. alveolata (Ulrich, 1893)
A. retrorsa Miller 1878
A. hyacinthensis (Foerste, 1924)

The environmental setting of *A. radiata* is treated under the discussion of *A. praecursa*. The common associated faunal elements are *Rafinesquina* "*alternata*", *Sowerbyella* (*Sowerbyella*) *sericea*, *Onniella multisecta*, crinoids and occasionally *Praenucula levata* and *Ctenodonta*? *pulchella*, all part of the *Sowerbyella–Onniella* Community.

Ambonychia praecursa (Ulrich, 1893)

Plate 37, figures 4-5; plate 38, figures 1-2, 4-5; plate 39, figures 1-4; plate 40, figures 1-4; plate 41, figures 1-3; plate 42, figures 3-4

Byssonychia praecursa Ulrich, 1893 (1895), p. 633, pl. 45, figs. 1, 2. Bassler, 1919, p. 283, pl. 57, figs. 28, 29. Stewart, 1920, p. 24, pl. 1, fig. 27. Foerste, 1924, p. 167, pl. 28, figs. 2a, b. Ruedemann, 1926, p. 30, figs. 9, 10. Pojeta, 1962, p. 191, pl. 27, figs. 1-7.

Byssonychia walkerensis Grabau, 1913, p. 454.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of medium size, strongly inflated, equivalved, broad posteroventral elongation (median diagonal of 234 specimens, 38 mm; median length, 25 mm).

Shape variable, length varying between 64 and 78 per cent of the diagonal (median of 234 specimens, 67 per cent). Byssal gap prominent, elliptical; byssal sinus shallow. Anterior margin almost flat, umbones not rounded. Surface sculpture of prominent radial ribs (35 to 40), some ribs bifurcating near the hinge line (Pl. 41, fig. 2); finer concentric striae, closely spaced, numerous; and prominent concentric striae, wide-spaced, very few. Cardinal teeth two, radiating from beneath umbo; lateral teeth two, short and confined to posterior end of hinge line. Ligament longitudinally striated, ligament area otherwise unknown. Internal features unknown. Original shell microstructure and mineralogy unknown.

MATERIALS. The description is based on over 1600 specimens from south-central Pennsylvania to southwestern Virginia deposited in the Peabody Museum.

DISCUSSION. The assignment of these specimens to *Ambonychia praecursa* conflicts with earlier central Appalachian reports in which assignment was made rather vaguely to *A. radiata*. A re-collection from a locality listed by Grabau (1913, my locality 140) has produced topotypes of *A. walkerensis* which are indistinguishable from *A. praecursa*.

Ulrich (1893, p. 633) in his original definition of *A.* (= *Byssonychia*) *praecursa* was unsure of its exact taxonomic status. He thought it could be either a true species or a variety of *A. richmondensis*, adding that *A. praecursa* could be the "forerunner" of *A. richmondensis*, *A. robusta* or *A. cultrata*, and was shaped like *A. radiata*. Most later authors have accepted *A. praecursa* as a true species. Unfortunately its systematic relationships to the other *Ambonychia* mentioned by Ulrich have never been discussed, and the size and shape variability that puzzled Ulrich has never been adequately defined.

In addition to *A. praecursa*, collections of *Ambonychia* specimens from central Appalachian Upper Ordovician rocks yield *A. radiata* and *A. cultrata*. An investigation of the general size-shape-variability of the three species points up a possible environmental control on distribution of the species. Medians of the diagonal and length, and the ratio of these two measurements from the central Appalachian specimens are shown in Table 19. The shell shape variations that exist among these three species of *Ambonychia* are diagrammed in Figure 32. Comparisons of shell morphology, abundant faunal associates, and substratum as determined from the central Appalachian species are shown in Table 20.

Table 20 and Figure 32 present a very simplified picture of *Ambonychia* shell morphology as it is probably related to the environmental setting. Each of the three species was most probably an epifaunal, byssally attached, mussel-like bivalve. The prominent byssal gap and equivalved form emphasize an attached upright mode of

TABLE 19. Measurements of the diagonal and length of the three common species of the genus *Ambonychia*. Of particular note is the length-diagonal ratio which is used as a general measure of shape variability and possibly related to environmental setting.

Species	Diagonal (mm)	Length (mm)	L/D (%)	N
A. praecursa	38	25	67	240
A. cultrata	51	37	78	26
A. radiata	24	20	82	12

TABLE 20. Comparisons of the morphology and abundant associated faunal elements of the genus *Ambonychia*. This table forms the basis for subsequent interpretations of central Appalachian Late Ordovician environmental setting (see also Fig. 32).

Species	*A. radiata*	*A. praecursa*	*A. cultrata*
Size	small	medium	large
Shape	subround	moderately elongate	subround
Byssal gap	small, ellipsoidal	large, ellipsoidal	large, elongate
Anterior edge	rounded	flat	flat
Dentition	weak	strong	unknown
Associated faunal elements	crinoids *Rafinesquina* *Praenucula* *Ctenodonta?*	*Modiolopsis* *Orthorhynchula* *Ischyrodonta*	*Modiolopsis* *Zygospira recurvirostra* *Pterinea* (*Caritodens*) Trepostomes
Populations	Orthid–Crinoid Population; *Sowerbyella–Onniella* Community	Modiolopsid and Rhynchonellid Populations; *Orthorhynchula–Ambonychia* Community	Spiriferid Population; *Zygospira–Hebertella* Community
Substratum	silty mud–mud	fine sand–silt	silty mud–mud

life. Pojeta (1962, p. 182) finds a Recent analogue in *Mytilus* and *Modiolus*; in overall shape, I believe, it also somewhat resembles *Pinna*. The fine sand and silt, where numerous *A. praecursa* are present, is interpreted as one of the most physically exposed environments in the central Appalachian Late Ordovician. *A. praecursa,* with its more elongate shape, broader and flatter anterior edge of attachment, and possibly more secure articulation seems the best adapted of the three to cope with such an environment.

Ambonychia praecursa grades abruptly southward into *A. cultrata.* There is an accompanying change in substratum from a fine sand-silt to mud. *Modiolopsis modiolaris* is the only faunal associate common to both species, whereas a small spiriferid brachiopod, *Zygospira recurvirostra*; a pterioid, *Pterinea* (*Cartiodens*) *demissa*; and trepostomes, part of the Spiriferid Population, *Zygospira–Hebertella* Community, are most common with *A. cultrata.* Mixtures of the two species are found at a few localities in south-central Virginia; but to the north only *A. praecursa* is found, and to the south, only *A. cultrata.* The larger, rotund shell shape and the narrow elongate byssal gap of *A. cultrata* appear better adapted to a less turbulent environment.

Ambonychia radiata is not much smaller than some *A. praecursa* but is similar to *A. cultrata* in shape (Table 19). Its rounded, small shell with a small byssal gap, is probably adapted for environments of little water movement. *A. radiata* is more common in a silty mud and mud (Table 20) that is characteristic of deposition in low-energy environments. The faunal associates and the stratigraphic and geographic distributions strengthen the interpretations of an exposed inner sublittoral setting for *A. praecursa* of the *Orthorhynchula–Ambonychia* Community, a protected inner sublittoral for *A. cultrata* of the *Zygospira–Hebertella* Community and an outer sublittoral for *A. radiata* of the *Sowerbyella–Onniella* Community.

Ruedemann (1926, p. 31) commented briefly that a slab from the New York Lorraine Group showed one *A. praecursa* with many *A. radiata.* This sort of association is common in central Pennsylvania, bivalve faunal province I, and suggests the

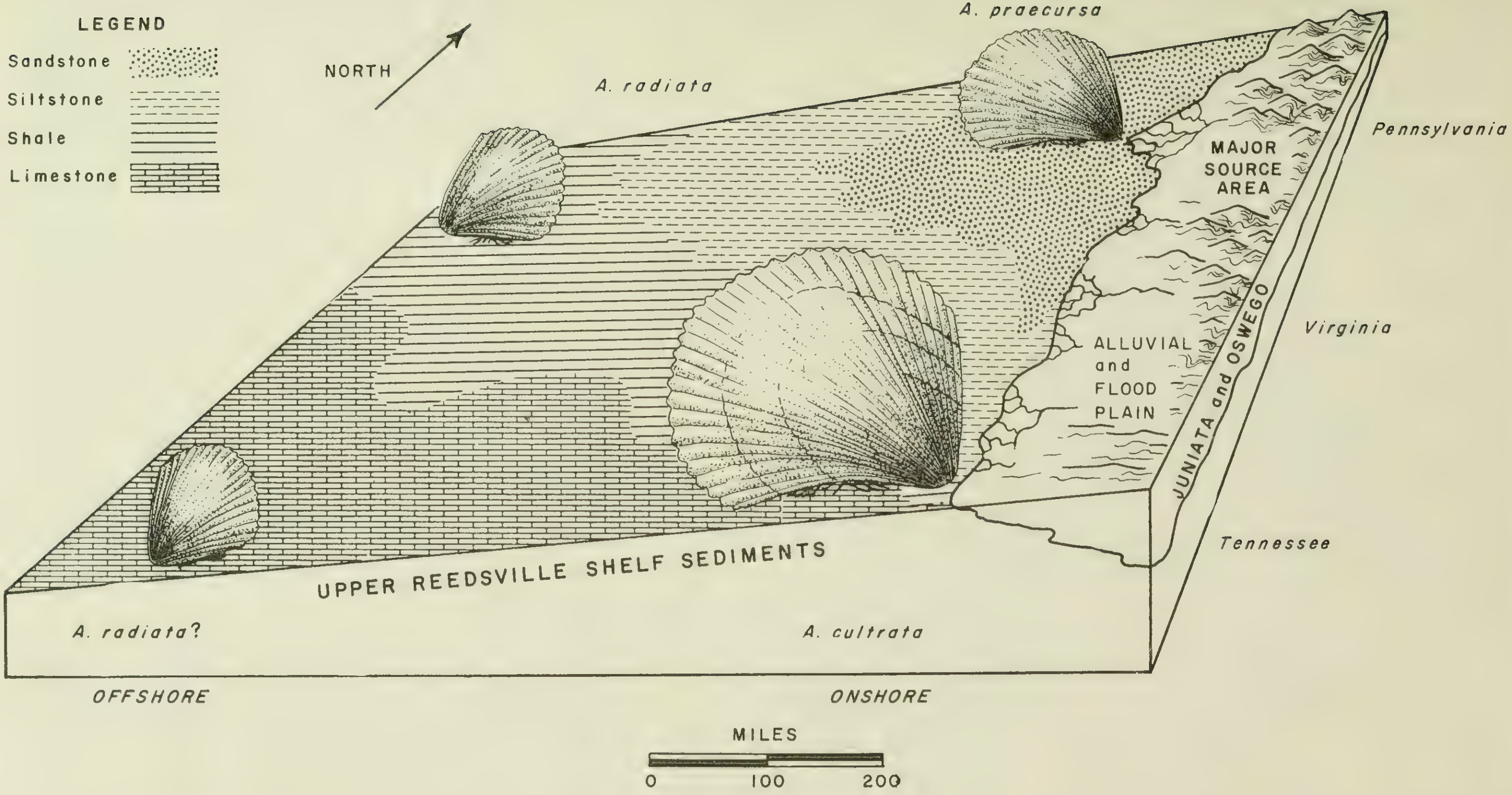
LEGEND
Sandstone
Siltstone
Shale
Limestone
NORTH
A. praecursa
A. radiata
Pennsylvania
MAJOR SOURCE AREA
ALLUVIAL and FLOOD PLAIN
JUNIATA and OSWEGO
Virginia
Tennessee
UPPER REEDSVILLE SHELF SEDIMENTS
A. radiata?
A. cultrata
OFFSHORE
ONSHORE
MILES
0
100
200

FIG. 32. Distribution of *Ambonychia* species during the Late Ordovician in the central Appalachians. Of particular note is the possibility of correlating morphological variability (i.e. general shape and size of valves) with environmental setting. Drawings of fossils are actual size of specimens. The scale refers to distance along the shore; onshore to offshore exaggeration ×4.

possibility of reworking a few dominantly inner sublittoral *A. praecursa* shells from the *Orthorhychula–Ambonychia* Community into outer sublittoral environs dominated by *A. radiata* of the *Sowerbyella–Onniella* Community. The opposite of this situation does not occur, in other words a few *A. radiata* have not been found with many *A. praecursa*, thereby possibly presenting some clue as to the relative strengths of the onshore and offshore current patterns. In fact, *A. praecursa* valves are also found within faunal assemblages dominated by numerous outer sublittoral faunal elements of the *Sowerbyella–Onniella* Community — brachiopods, crinoids and bryozoans.

Ambonychia praecursa is by far the most widely distributed *Ambonychia* in the Upper Ordovician clastic facies, bivalve faunal province II (Fig. 17). The usual faunal associates are *Modiolopsis modiolaris* and/or *O. linneyi* of the Modiolopsid and Rhynchonellid Populations of the *Orthorhynchula–Ambonychia* Community, but at three widely separated localities (Table 3, loc. 78, 152 and 203) specimens which resemble *A. praecursa*, *A.* cf. *praecursa*, are found with numerous *Tancrediopsis cuneata*, *Lingula*? and *Plectonotus*? sp., part of the Linguloid Population of the *Orthorhynchula–Ambonychia* Community. These specimens have not been included in the description of central Appalachian *A. praecursa*. Twelve specimens of *A.* cf. *praecursa* show a median diagonal of 19 mm, almost half that of the central Appalachian *A. praecursa*. From all available stratigraphic, sedimentological and paleontological evidence, species of the Linguloid Population probably dominated the nearest-shore Upper Ordovician environments. If these specimens are dwarfed *A. praecursa*, it is likely that the control may be in reduced or variable salinity (see Hallam, 1965, p. 134).

Ambonychia cultrata (Ulrich, 1893)

Plate 42, figures 1, 2; plate 43, figures 1-4

Byssonychia cultrata Ulrich, 1893 (1895), p. 632, pl. 45, figs. 5-7. Foerste, 1924, p. 166, pl. 28, fig. 6. Pojeta, 1962, p. 189, pl. 25, figs. 6-13, pl. 26, figs. 1-6.
Ambonychia cultrata (Ulrich). Pojeta, 1966, p. 174, pl. 32, figs. 1, 2.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of large size, slight to moderate inflation, broad posteroventral expansion (diagonal dimension of 15 specimens, 51 mm; median length, 39 mm). Shape variable, length varying between 74 and 81 per cent of the diagonal (median of 15 specimens, 78 per cent). Byssal gap narrow, elongate; byssal sinus moderate. Anterior margin flat, umbones not rounded. Surface sculpture of prominent radial ribs (40 to 45); less prominent fine concentric striae. Dentition unknown. Ligament broad, elongate, longitudinally striated, ligament area otherwise unknown. Internal features unknown. Original shell microstructure and mineralogy unknown.

MATERIALS. The description is based on over 40 specimens from southwestern Virginia and northern Tennessee deposited in the Peabody Museum.

DISCUSSION. The assignment of these specimens to the genus *Ambonychia* is tentative, for internal features and dentition are lacking. General shell shape and size suggest that this central Appalachian species is conspecific with the types of Ulrich's *Byssony-*

chia cultrata from Ohio. The environmental setting of the central Appalachian Upper Ordovician specimens of *A. cultrata* has been outlined under the discussion of *A. praecursa* (p. 119). *A. cultrata* is common only in southwestern Virginia and northern Tennessee, bivalve faunal province III (Fig. 17). The more northerly localities (Table 3, loc. 145, 147, 149, 151, 184) contains a mixture of *A. cultrata* and *A. praecursa*, but farther to the south *A. cultrata* is the dominant *Ambonychia*. It may occur entirely without *A. praecursa*, but is commonly found (loc. 131, 133, 140, 141) with a fauna dominated by *Modiolopsis modiolaris*, *Zygospira recurvirostra*, *Pterinea* (*Caritodens*) *demissa* and *Monticulipora*, from the Spiriferid Population of the *Zygospira–Hebertella* Community.

?*Ambonychia byrnesi* (Ulrich, 1893)

Plate 38, figure 3

Byssonychia(?) *byrnesi* Ulrich, 1893 (1895), p. 635, pl. 47, figs. 4, 5.
Byssonychia cf. *byrnesi* (Ulrich). Foerste, 1914b, p. 134, pl. 3, fig. 6.
Byssonychia byrnesi (Ulrich). Pojeta, 1962, p. 188, pl. 25, figs. 2-5.
Ambonychia byrnesi (Ulrich). Pojeta, 1966, p. 142, pl. 31, figs. 18-20.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of medium size, strongly inflated, broad posterior expansion (median diagonal of three specimens, 43 mm, length one specimen, 36 mm). Shape variability unknown (length 84 per cent of diagonal in one specimen). Byssal gap small, elliptical; byssal sinus slight. Anterior margin rounded, umbones rounded. Surface sculpture of prominent radial ribs, about 25; fine concentric striae with a few widely spaced prominent concentric striae. Dentition unknown. Ligament area unknown. Shell microstructure and mineralogy unknown.

Materials. The description is based on three specimens from central Pennsylvania deposited in the Peabody Museum.

Discussion. The identification of these few specimens as *Ambonychia byrnesi* is tentative. The generic status is in doubt because no internal features are preserved, and differentiation from *A. actirostris* and *A. imbricata* is uncertain because the shell shape variation is unknown.

The specimens come from only one locality (Table 3, loc. 75) and are unlike any other *Ambonychia* in the central Appalachian Upper Ordovician strata in the strength and numbers of radial ribs. Associated with the more common *A. praecursa* in a muddy silt, near what appears to be the northern extreme of the *A. praecursa* distribution, bivalve faunal province II (Fig. 17), their general inflated shell shape, rounded appearance and small byssal gap appear to be suited to a lower energy environment than is indicated by the elongate *A. praecursa* with a large byssal gap. These specimens were not included in the simplified ecological picture presented under the discussion of *A. praecursa* because they are so few in number. *A. praecursa* in this northern environment does show some shape variability, becoming somewhat larger but no less elongate; but I am sure that these specimens called ?*A. byrnesi* could not be included within the variability limits of *A. praecursa*.

SUPERFAMILY PTERIACEA
FAMILY PTERINEIDAE
GENUS *PTERINEA*

Pterinea (*Caritodens*) *demissa* (Conrad, 1842)

Plate 24, figures 5-7; plate 25, figures 1-5; plate 26, figures 1-7;
plate 27, figures 1, 2

Avicula demissa Conrad, 1842, p. 242, pl. 13, fig. 3. Emmons, 1842, p. 404, fig. 2. Hall, 1847, p. 292, pl. 80, figs. 2a, b. Emmons, 1855, p. 175, pl. 17, fig. 10.

Pterinea demissa (Conrad). McCoy, 1854, p. 260, pl. 1, fig. 7. Hall and Whitfield, 1875, p. 78, pl. 2, fig. 1. Cumings, 1908, p. 1018, pl. 48, fig. 1. Stewart, 1920, p. 22, pl. 1, fig. 28.

Pterinea (*Caritodens*) *demissa* (Conrad). Foerste, 1910, p. 71, pl. 1, fig. 10. Bassler, 1919, p. 284, pl. 57, fig. 24. Foerste, 1924, p. 161, pl. 26, fig. 3; pl. 29, fig. 10; pl. 31, fig. 12. Ruedemann, 1926, p. 23, figs. 7-11.

Caritodens demissa (Conrad). Foerste, 1914a, p. 269, pl. 1, fig. 10; pl. 3, fig. 11.

[?]*Pterinea maternata* Secrist and Evitt, 1943, p. 365, fig. 15.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of medium size (median length of 36 specimens, 25 mm; median height of 49 specimens, 22 mm), inequivalved. Left valve convex; right valve slightly convex in umbonal region, flat to slightly concave marginally. Shape extremely variable, height ranging from 60 to 123 per cent of the length (median of 33 specimens, 94 per cent); angle formed by line drawn along the mid-part of the umbonal ridge and hinge line ranges between 55 and 75 degrees (median of 34 specimens, 65 degrees); lowest angle and obliquely prosoclinal shape most common in smaller specimens (Pl. 24, fig. 7, and Pl. 25, fig. 2); larger shells usually obtuse, rounded (Pl. 25, fig. 1, and Pl. 28, fig. 1). Byssal sinus on anterior margin, near hinge line, not pronounced. Anterior auricle and posterior wing, blunt, rounded, length of both variable. Umbones prominent, broad, rounded; posterior margin of umbonal ridge distinct, sharp subangular; anterior part broadly rounded, less prominent than posterior. Surface sculpture of two kinds of concentric striae: coarse, raised, irregular, widely spaced; and fine, regular, closely spaced. Posterior lateral tooth on left valve, corresponding socket on right valve, gently concave toward umbonal ridge, elongate; possible anterior tooth on left valve, short, projecting just beneath and anterior to umbones. Ligament duplivincular, six to eight fine longitudinal striae, amphidetic, narrow, internal. Posterior adductor large, sub-round, located centrally between ventral and dorsal margins, preserved on one right valve. All other internal features unknown. Original shell microstructure and mineralogy unknown.

MATERIALS. The description is based on over 80 specimens from West Virginia and Virginia deposited in the Peabody Museum.

DISCUSSION. The assignment of these central Appalachian Upper Ordovician specimens to *Pterinea* (*Caritodens*) *demissa* is tentative, because of both the small amount of well-preserved Ordovician material upon which the taxon is defined and, especially, the lack of recent taxonomic studies of lower Paleozoic pterioids.

Foerste (1910, p. 71) established the subgenus *Caritodens* (which he later raised to generic rank) for what he believed to be a distinct Upper Ordovician pterioid that could be distinguished from *Pterinea* by the absence of the duplivincular ligament and of well-defined multiple anterior and posterior teeth. The type, *C. demissa* (Conrad), exhibits only one strong posterior "crural" ridge, or "jugum", which culminates in a posterior lateral tooth, and also a short, blunt anterior projection. Subsequently Foerste (1914a, p. 269) discovered better preserved Ordovician material that showed a definite duplivincular ligament. Thus the definition of *Caritodens* rests solely on the presence of the single "crural" ridge.

Foerste had failed to figure *C. demissa* with the posterior "crural" ridge and the loss of the material prior to his 1924 publication makes the documentation less well-established. Ruedemann, however, figured a New York specimen (1926, pl. 2, fig. 8) that does show the characteristic posterior jugum, which I have found to be typical in all my central Appalachian Upper Ordovician material.

One of the major problems facing the earlier investigators in the definition and identification of Ordovician pterioids, aside from the characteristic poor preservation, was the extreme shape variation. The definition of a number of Ordovician species was based on slight changes in shape or minor differences in the concentric surface sculpture. The following is a list of North American Ordovician pterioid species that may be junior subjective synonyms of *P.* (*C.*) *demissa.*

Pterinea insueta (Emmons)
P. obtusiformis Ruedemann
P. cincinnatiensis Miller and Faber
P. rugatula Miller and Faber
P. prolifica Billings
P. bellilineata Billings
P. macronota Ulrich

Secrist and Evitt (1943, p. 365, fig. 15) figured a very poorly preserved specimen called *P. maternata* that was collected from their Passage Creek locality at Massanutten Mountain, north-central Virginia. I have re-collected from this locality (loc. 167) and do not feel that my material can be satisfactorily distinguished from *P.* (*C.*) *demissa.*

The problem of shell shape and its significance as a discriminator of species was the topic of lengthy discussions by Foerste (1914a, p. 269; 1924, p. 161) and of a summary statement, with illustrations, by Ruedemann (1926, p. 24-25). Without any knowledge of possible allometric growth in Recent pterioid species, Foerste introduced the idea that the younger, smaller *P.* (*C.*) *demissa* are characteristically more oblique, whereas the more mature, larger specimens are more ovate. He concluded that the direction of maximum growth along the shell edge changed drastically through time; "Small specimens appear so different from mature ones as to suggest their belonging to a different species" (Foerste, 1924, p. 161). However, Hynd (1955), working with the Recent *Pinctada albina*, an abundant pterioid found along the coastline of northern Australia, confirmed this dramatic change in shell shape with age, and found that every one of the taxonomic shape characters usually described is subject to considerable change.

Unfortunately Foerste had discovered only about half of the problem; it becomes increasingly apparent from the numbers of central Appalachian Upper Ordovician specimens which I have collected that supposedly mature specimens from the same horizon may be ovate or oblique (Pl. 25, fig. 1, and Pl. 26, fig. 6). Again, Hynd (1960) described quite significant morphological changes in the shape of *Pinctada albina* as a result of environmental influences. He did not relate these changes in the character of the shell to any clearly defined environmental conditions. Added to the characteristic allometric growth that invariably shows a pronounced oblique juvenile shell, middle-sized erect specimens and large obtuse forms, Hynd (1960) found that pterioid shells assumed two extreme shapes as the result of environmental influences. One group, found in a "rocky environment" and attached to a hard subsurface, exhibits a relatively stronger projection of the anterior margin and the posterior wing; the posteroventral margin does not project and the shell form is obtuse. The second group, presumably the sandy-bottom dwelling, inner sublittoral specimens, shows no noticeable projection of the anterior margin or of the posterior wing; rather, the posteroventral margin projects strongly and the shell form is oblique or erect. Pterioids from the central Appalachian Upper Ordovician rocks exhibit the obtuse and oblique shell forms as a function of size and possibly of ecological control.

Pterinea (*Caritodens*) *demissa* is one of the most widespread faunal elements in the central Appalachian Upper Ordovician strata, but is abundant only in southwestern Virginia, bivalve faunal province III (Fig. 17 and Table 3, loc. 141, 147, 149, 184). Here it occurs in a silty mud with numerous *Zygospira recurvirostra*, *Ambonychia cultrata*, various trespostomatous Bryozoa and some *Hebertella sinuata*, all part of the Spiriferid Population of the *Zygospira–Hebertella* Community. In these localities where *P.* (*C.*) *demissa* is common both right and left valves are found. In the more northerly exposures where fewer valves are found, only the more convex left valve occurs. Bassler (1919), Foerste (1910, 1914a, 1924) and Ruedemann (1926) have figured only left valves, and Ruedemann (1926, p. 26) thought that the right valve may have been in some way less resistant. The right valves may have been more delicate, more easily fragmented by currents, and thus more readily lost through the effects of diagenesis and compaction. Another possibility, perhaps less likely, is that of differential shell transport. The plate-shaped, probably lighter right valves may have been more easily winnowed and scattered by waves and currents, whereas the convex left valves, larger and somewhat heavier, would tend to remain aggregated and be preserved essentially in place.

Inferences as to life habitats of the central Appalachian Upper Ordovician *P.* (*C.*) *demissa* come from the spare literature available on Recent pterioids. Although there is a fair amount of data concerning their anatomy, there are few references to ecology and environmental setting. Modern pterioids appear to live in a variety of shallow and deep water environments, although they appear most prolific in the inner sublittoral. Attached to a firm sandy substratum or solid object (e.g., reefs, rocks, pilings) by the convex right valve, they exhibit a pronounced byssal notch in the right valve. Newell (1937, p. 18–20) discussed the enigma that no known Paleozoic pterioids or pectinoids have a markedly convex right valve. As is the case in the Ordovician *P.* (*C.*) *demissa*, the right valve is only slightly convex and is, in fact, partially concave at the margin. The byssal notch in the right valve of *P.* (*C.*) *demissa* is no more pronounced than that in the left valve. Whether these Ordovician pterioids rested on their convex left or "flat" right valve remains unknown.

The probable environmental setting for *P.* (*C.*) *demissa* is an inner sublittoral, quiet, non-turbid environment where wave and current energy was only strong enough to winnow and scatter the more delicate right valves. The pterioids definitely thrived away from the more northerly influx of clastic terrigenous sediments. There is no significant geographic trend in the shape of *P.* (*C.*) *demissa* shells, although there are more numerous oblique shells in the southwestern Virginia localities where the pterioids are most abundant. This is the more common shell form for Recent pterioids living on "sandy" bottoms and not attached to a hard substratum. The pronounced alate form apparently common in the Upper Ordovician of southeastern Canada and figured by Foerste (1914a, 1924) is, however, not common in the central Appalachian clastic facies or in the New York Upper Ordovician Lorraine Group (Ruedemann, 1926, p. 25).

SUBCLASS PALAEOHETERODONTA
ORDER ACTINODONTOIDA
SUPERFAMILY MODIOMORPHACEA
FAMILY MODIOMORPHIDAE
GENUS *MODIOLOPSIS*

Modiolopsis modiolaris (Conrad, 1838)
Plate 31, figures 1-3; plate 32, figures 1-3; Plate 33, figures 1-3;
Plate 34, figures 1-3; plate 35, figures 1-4

Pterinea modiolaris Conrad, 1838, p. 118.

Cypricardites modiolaris (Conrad). Conrad, 1841, p. 52. Emmons, 1842, p. 403, [?]fig. 4; p. 405, fig. 114.2.

Cypricardites augustifrons Conrad, 1841, p. 52. Emmons, 1842, p. 405, fig. 114.1.

Cypricardites ovata Conrad, 1841, p. 52.

Modiolopsis modiolaris (Conrad). Hall, 1847, p. 294, pl. 81, fig. 1a-1g, [?]pl. 82, fig. 1. Billings, 1856, p. 44, fig. 8. Billings, 1863, p. 213, fig. 217. Ulrich, 1894, p. 481, figs. 37a, [?]37b. Bassler, 1909, pl. 14, fig. 8. Foerste, 1914a, p. 281, pl. 3, fig. 1; pl. 5, figs. 1, 2. [not]Hall and Whitfield, 1875, p. 83, pl. 2, fig. 17. Bassler, 1919, p. 286, pl. 58, fig. 12. Stewart, 1920, p. 34, pl. 3, fig. 1.

Lysonia submodiolaris (d'Orbigny). Emmons, 1855, p. 171, pl. 17, figs. 8, 8a.

Modiodesma modiolare (Conrad). Ulrich, 1924, p. 191, pl. 31, fig. 1; pl. 32, figs. 1-3; pl. 33, figs. 3-6. Ruedemann, 1925a, pl. 6. Ruedemann, 1926, p. 32, pl. 4.

Modiodesma modiolare var. *augustifrons* (Conrad). Ulrich, 1924, p. 189, pl. 32, figs. 4, 5. Ruedemann, 1926, p. 34, fig. 11.

Modiodesma modiolare var. *brevoir* Ulrich, 1924, p. 189. Ruedemann, 1926, p. 34.

[?]*Modiodesma scapha* Ulrich, 1924, p. 189, pl. 33, figs. 1, 2.

[?]*Orthodesma* sp.? Butts, 1941, p. 114, pl. 96, figs. 19, 20.

[?]*Rhytimya* sp.? Butts, 1941, p. 127, pl. 100, fig. 1; p. 128, pl. 100, figs. 14, 15.

[?]*Whiteavesia* sp.? Butts, 1941, p. 127, pl. 100, fig. 16.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of large size (median length of 154 specimens, 51 mm, median height of 171 specimens, 20 mm), inflated, equivalved, extreme posterior elongation. Shape variable, height varying between 19 and 62 per cent of the length (median of 120 specimens 42 per cent), much of shape variation results from tectonic distortion (Pl. 35, fig.

4; cf. Ulrich, 1894, p. 481, figs. 37a, b). Byssal sinus shallow, on ventral margin, toward anterior. Umbones rounded, near anterior margin; umbonal ridge faint, broadly rounded, flattens toward posterior. Anterior margin sharply rounded, narrow; posterior margin broadly rounded, expanded. Surface sculpture of fine concentric striae, preserved as external mold, over entire shell, most prominent at postero- and anterodorsal margins. Edentulous. Ligament broad, elongate, straight to moderately curved, opisthodetic, possibly partially internal. Anisomyarian, anterior adductor large, subcircular to elongate, narrowing at dorsal edge; posterior adductor two times larger than anterior, very faint, subcircular. Pedal retractors small, elongate, directly above anterior adductor. All other internal features unknown. Shell microstructure and mineralogy unknown.

MATERIALS. The description is based on over 850 specimens from south-central Pennsylvania to northern Tennessee deposited in the Peabody Museum.

DISCUSSION. The assignment of these central Appalachian Upper Ordovician specimens to *Modiolopsis modiolaris* is tentative pending a restudy of *Modiolopsis* Hall, *Orthodesma* Hall and Whitfield, and *Cymatonota* Ulrich.

Hall (1847, p. 297) combined *Pterinea modiolaris* (= *Cypricardites modiolaris*) Conrad, *Cypricardites angustifrons* Conrad and *Cypricardites ovata* Conrad to form *Modiolopsis modiolaris*, which was defined as the type of Hall's new genus *Modiolopsis*. In the definition of *M. modiolaris*, Hall placed a great deal of emphasis on the extreme shape variability of the New York Ordovician specimens. This variability was thought to result from "natural" and "compressional" forces. Hall probably attributed to "natural forces" the distinct shape variation between forms found in shales and those in sandstones, although he failed to mention specifically what the characteristic changes were. The secondary tectonic or "compressional" forces that altered the original shell shape were documented by Ulrich (1894, p. 481, figs. 37a, b; Pl. 35, fig. 4, this paper). Distorted *M. modiolaris* and other associated faunal elements are common at most localities in the central Appalachians.

Ulrich (1924, p. 183) reviewed Hall's type material and attempted to redefine *M. modiolaris* but incorrectly made it the type of a new genus *Modiodesma*. Ulrich claimed that *Modiolopsis modiolaris* had to be removed from the genus *Modiolopsis* because it did not conform to Hall's generic definition. *Modiodesma modiolaris* must be considered a junior objective synonym of *Modiolopsis modiolaris*. It is certainly possible that Hall's material contained more than one species, but I doubt that Ulrich's division of *Modiolopsis modiolaris* into four separate species representing three genera can be substantiated. I do feel, however, that Hall's (1847) pl. 82, fig. 1 is probably not *Modiolopsis modiolaris*. Whether it is another species of *Modiolopsis* (*M. milleri*?) or a species of *Colpomya* must await a more complete taxonomic revision.

Newell et al. 1969 have placed the genus *Modiodesma* in synonymy with *Modiolopsis* and have added a number of junior subjective synonyms; one is the genus *Orthodesma* Hall and Whitfield, which has been identified previously in the central Appalachian Upper Ordovician rocks as occurring with *M. modiolaris* (Foerste, 1914a, p. 284-285). Hall and Whitfield (1875, p. 93) defined *Orthodesma* as differing from *Modiolopsis* in the absence of hinge teeth; Ulrich (1894, p. 516) emphasized the edentulous nature of *Orthodesma* and its close relationship to *Modiolopsis*, but felt that the elongate outline, coarser concentric striae and slightly gaping valves were typical of *Orthodesma*. I have found in the central Appalachian material that misidentification of *Modiolopsis modiolaris* as *Orthodesma rectum* or *O. nasuta* is simply a function of distortion and selective preservation. The coarser concentric striae are preserved only as an external mold of *M. modiolaris*, and the distortion gives rise to the elongate outline and the gaping valves. I am in complete agreement, however, with John Pojeta of the U. S. Geological Survey (pers. comm.) that some gaping, elongate *Orthodesma*-like bivalves in the Ordovician are distinct from what I believe to be deformed *Modiolopsis*. A complete review of the Family Modiomorphidae Miller 1877 (=Modiolopsidae Fischer 1887) should resolve these problems.

Modiolopsis modiolaris is one of the most common central Appalachian Upper Ordovician faunal elements and is abundant from south-central Pennsylvania to south-central Virginia, bivalve faunal province II (Fig. 17). Associated faunal elements are normally *Ambonychia praecursa* and, rarely, *Orthorhynchula linneyi* (Ruedemann, 1925a, p. 6; Pl. 2, this paper), both in the Modiolopsid and Rhynchonellid Populations of the *Orthorhynchula–Ambonychia* Community. Patches of abundant *M. modiolaris* occurring alone appear common in central Virginia. The substratum is usually a muddy silt-sand, and the patches of concentrated, exclusively *M. modiolaris* are found in a muddier sediment. But most of the *M. modiolaris* are not clumped but are scattered over the bedding plane, where the valves are often articulated and in various degrees gaping.

In southwestern Virginia and northern Tennessee, bivalve faunal province III (Fig. 17), *M. modiolaris* is a less dominant faunal element, usually smaller (length normally less than 30 mm), less notably elongate and more rectangular (Pl. 35, fig. 2). It resembles *M. concentrica*; but I feel that these morphological differences are slight in light of the poor preservation of the southern material and the present wide range of shape variation permitted in *M. modiolaris*. The substratum is a silty mud in southwestern Virginia and the common associated faunal elements are *Ambonychia cultrata*, *Zygospira recurvirostra* and *Dekayia* in the Spiriferid Population of the *Zygospira–Hebertella* Community (Table 3, loc. 149, 151, 141). In the lime muds of northern Tennessee, *M. modiolaris* is found with abundant *Zygospira recurvirostra*, *Hebertella sinuata* and a few *Ambonychia radiata*?.

Scattered modiolopsids, possibly *M. sinuata* (= *M. anodontoides*?; Pl. 32, fig. 2) are found with abundant *Onniella multisecta*, crinoids and *Lyrodesma poststriatum* from the Orthid–Crinoid Population of the *Sowerbyella–Onniella* Community in north-central Pennsylvania, bivalve faunal province I (Fig. 17). A few small *Colpomya* and *Cymatonota* (= ?*Psiloconcha*) are occasionally found with abundant crinoids in the same general area. Very poorly preserved modiolopsids occur along the eastern edge of the Reedsville exposures in north-central Virginia bivalve faunal province I (loc. 167, 168, 169), where they are found with abundant *Rafinesquina* "*alternata*", numerous pleurotomariacean gastropods and a few *Cyrtodonta*? (Pl. 37, figs. 1-3), part of the Strophomenid Population of the *Sowerbyella–Onniella* Community. The state of preservation of these modiolopsid-like bivalves precludes even a tentative generic assignment.

The environmental setting and life habits of *M. modiolaris* probably were much like those of some recent species of *Modiolus*. One, *Modiolus rectus*, found along the west coast of the United States, is bysally attached in the muddy silts and sands of quiet water, nearshore environments. The mussel is usually solitary and occasionally is found covering a fairly extensive mud-silt flat, or muddy substratum in 5 to 15 meters of water. It is embedded vertically in the mud with just the posterior tip of the shell projecting above the surface (Fitch, 1953, p. 48; Keen, 1958, p. 56). Small clumps or patches of the related *Modiolus modiolus* have also been reported by Kuderskii (1962) from the inner sublittoral waters of Onega Bay, the White Sea, U.S.S.R.

The central Appalachian Upper Ordovician *M. modiolaris* is believed to have inhabited a quiet water, inner sublittoral environment, living bysally attached, usually solitary and partially embedded in the muddy silt substratum. Where abundant *M. modiolaris* is found alone and not in common association with *Ambonychia praecursa* there is usually a change in the substratum, from a muddy silt to a silty mud. This mud may place a limitation on the distribution of the subround ambonychiid but not on that of the more elongate modiomorphid which may, in fact, have lived embedded even more deeply in the muds. I have found little evidence to support the clumping of *M. modiolaris* into a shell bank. Rare large concentrations of articulated valves may reflect clumping or may have been produced by local current activity. Mortality-growth rate curves may provide further clues to the possibilities of transportation prior to burial.

M. modiolaris shows some evidence of infestations by *Polydora*-like worms; occasionally a few specimens exhibit a characteristic, irregular "U"-shaped worm tube at the approximate position of the inhalent current (Pl. 31, fig. 1). This infestation is never extensive and probably had little influence on the distribution of *M. modiolaris.* And most often the posterior portion of the shell extends beyond the tube, probably indicating an adequate relining of shell material over the tube. One interesting note is that collections of *M. modiolaris* in the Peabody Museum from the Upper Ordovician of the Cincinnati region occasionally show identical inhalent worm tubes. Boekschoten (1966, p. 354), working along the Dutch tidal flat, described Recent *Polydora* tubes at the posterior margins of some *Cardium edule*, which appears to be indicative of attack in living position. Only where the valves were separated and lying loose on the substratum were they bored over the entire surface.

[?]ORDER TRIGONIOIDA
[?]SUPERFAMILY LYRODESMATACEA
[?]FAMILY LYRODESMATIDAE
GENUS *ISCHYRODONTA*

Ischyrodonta truncata Ulrich, 1890

Plate 27, figures 3-6; plate 28, figures 1-6; plate 29, figures 1-6;
plate 30, figures 1-6

[?]*Modiolopsis truncatus* Hall, 1847, p. 296, pl. 81, figs. 3a, b. Hall and Whitfield, 1875, p. 86, pl. 2, fig. 13.

[?]*Lysonia subtruncata* (d'Orbigny). Emmons, 1855, p. 171, pl. 17, fig. 4.

Ischyrodonta truncata [not Hall, 1847] Ulrich, 1890, p. 174, figs. 11a-11e. Ulrich, 1893, p. 672, figs. 1a-1e.

[?]*Ischyrodonta ovalis* Ulrich, 1892, p. 242, fig. 27. Ulrich, 1893, p. 674, pl. 54, figs. 12-15. Ulrich, 1894, p. 477, fig. 35-I.

[?]*Ischyrodonta decipiens* Ulrich, 1893, p. 673, pl. 45, figs. 16-19.

[?]*Modiolodon truncatus* (Hall). Ulrich, 1893, p. 656, pl. 51, figs. 9, 10. Bassler, 1919,

p. 288, pl. 57, fig. 25. Ruedemann, 1926, p. 39. Butts, 1941, p. 127, pl. 100, figs. 2, 3.

[?]*Eurymya? truncata* (Hall). Ulrich, 1894, p. 512.

[?]*Modiolopsis* sp.? Butts, 1941, p. 127, pl. 100, figs. 12, 13.

Description Based on Specimens from the Central Appalachian Upper Ordovician. Shell of medium size (median length of 78 specimens, 29 mm; median height of 107 specimens, 17 mm), inflated, inequivalved, broad, posterior expansion. Shape sub-trapezoidal, variable, height varying between 50 and 70 per cent of the length (median of 73 specimens, 61 per cent); distance umbo to anterior margin varying between 22 and 45 per cent of total shell length (median of 73 specimens, 32 per cent). Byssal sinus very faint. Anterior margin broadly rounded; posterior margin flattened, wide, intersection with hinge line sharply rounded. Umbones prominent, sharp, gently pointed toward anterior, curved in toward hinge line; umbonal ridge broad, subangular. Surface sculpture prominent, concentric striae, coarse, widely spaced. Cardinal teeth usually two, radiating from beneath umbo; lateral teeth unknown. Ligament duplivincular, two or three longitudinal striae, narrow, internal, amphidetic (Pl. 30, fig. 6). Anisomyarian; anterior adductor muscle large, elongated dorsoventrally, subround, with coarse longitudinal furrows; posterior adductor faint, subcircular, twice as large as anterior muscle. Pedal retractor muscle prominent, small, rounded, directly above but separated from anterior adductor. All other internal features unknown. Original shell microstructure and mineralogy unknown.

Materials. The description is based on over 250 specimens from Pennsylvania to Tennessee deposited in the Peabody Museum.

Discussion. The assignment of these central Appalachian Upper Ordovician specimens to *Ischyrodonta truncata* is tentative pending a complete taxonomic restudy of *Ischyrodonta*, *Modiolodon*, *Ortonella*, *Cyrtodonta* and *Modiolopsis*. The strong, well-defined cardinal teeth and the duplivincular ligament presumably set *Ischyrodonta* apart from *Modiolopsis*. The lack of any posterior lateral teeth probably separates it from *Cyrtodonta* and *Ortonella*, but *Ischyrodonta* Ulrich (1890, p. 173) and *Modiolodon* Ulrich (1893, p. 652; 1894, p. 521) had been considered indistinguishable.. However John Pojeta (pers. comm.) has informed me that silicified topotypic *Modiolodon* material does not show a duplivincular ligament.

Bassler (1919, pl. 57, fig. 25) and Butts (1941, pl. 100, figs. 2, 3, 12, 13) have figured poorly preserved specimens from the central Appalachian Upper Ordovician rocks, which they called *Modiolodon truncatus* and *Modiolopsis* sp.?, that resemble the specimens I have collected from the same area. Ruedemann (1926, p. 39), however, claimed that *M. truncatus* is exclusively an Ohio Valley species and that the New York, Appalachian and Canadian specimens misidentified as this species are really *Ischyrodonta* (= *Anodontopsis*) *unionoides*, a possibility that had been touched upon briefly by Hall and Whitfield (1875, p. 86). The reasons for his reassignment are not clear, although Ulrich (1890, p. 173; 1894, p. 521) suggested the supposedly thicker shell and well-preserved pedal muscle scars, common to the Appalachian specimens, are more characteristic of *Ischyrodonta* than *Modiolodon* or *Cyrtodonta*.

Ischyrodonta unionoides has been reported frequently from the Upper Ordovician rocks of eastern North America (Ulrich, 1893; Foerste, 1914a, 1924; Bassler, 1919;

Stewart, 1920; Ruedemann, 1926), but all the figured specimens are considerably more ovate than the specimens I have collected and have assigned to *I. truncata*. In fact, *I. truncata* seems to present something of an intermediate subtrapezoidal shape between the rounded *I. unionoides* and the notably elongate *I. elongata* Ulrich (1890), *I. miseneri* Ulrich (1893) and *I. modioliformis* Ulrich (1893).

Ischyrodonta truncata is one of the most common and widespread faunal elements in the central Appalachian Upper Ordovician. It is most abundant from south-central Pennsylvania to southern Virginia, bivalve faunal province II (Fig. 17), and is associated with two distinct faunal populations. In one case *O. linneyi* from the Rhynchonellid Population of the *Orthorhynchula–Ambonychia* Community is the most abundant associated faunal element. *I. truncata* is also found associated with *Tancrediopsis cuneata, Lingula*? and *Plectonotus*? sp., part of the Linguloid Population of the *Orthorhynchula–Ambonychia* Community, although *O. linneyi* rarely occurs with these. The substratum in both cases is a muddy silt-fine sand. Smaller numbers of *I. truncata* are found with abundant *Rafinesquina* "*alternata*", *Onniella multisecta*, crinoids, *Hallopora*, and *Lyrodesma poststriatum*, part of the Orthid-Crinoid Population of the *Sowerbyella–Onniella* Community, in north-central Pennsylvania (Table 3, loc. 77-A, 110) in a fine muddy silt, and in southwestern Virginia and northern Tennessee (loc. 141, 147, 133, 135, 139) with abundant *Zygospira recurvirostra, Pterinea* (*Caritodens*) *demissa*, *Murchisonia*? and various trespostomatous Bryozoa, part of the Spiriferid Population of the *Zygospira–Hebertella Community*, in a fine silty mud.

The life habits of *I. truncata* may have resembled those of some Recent *Modiolus* (especially *M. capax*), to which *I. truncata* shows a superficial resemblance. The environmental setting probably was similar to that proposed for *Modiolopsis modiolaris*, in which the mussel lived byssally attached to a silt-sand substratum, partially submerged in a quiet, semi-protected, inner sublittoral environment. The distribution rarely shows clumping of individuals. Sardeson (1924) provided evidence for the possibility of an infaunal habit for some mid-continent *Cyrtodonta*, to which *I. truncata* shows at least some resemblance in shape, musculature and cardinal dentition. *I. truncata* may therefore have assumed a partially submerged habit especially in the nearer shore, possibly more turbulent environments. Some tolerance for temporary changes in salinity may be indicated by its association with abundant *Lingula*? and *Tancrediopsis cuneata*. Association with abundant *O. linneyi* probably points to a more normal marine environment. Locally common in *I. truncata*, when associated with *O. linneyi*, is the preservation of what appears to be worm tubes at the inhalent opening (Pl. 28, fig. 3; Pl. 29, fig. 3). Tubes of this type are also commonly found preserved on *O. linneyi* valve margins at the probable sites of inhalent currents (Pl. 14, fig. 1). The ecological significance of this infestation was probably minimal.

Genus *LYRODESMA*

Lyrodesma poststriatum (Emmons, 1842)
Plate 44, figures 1-7

Nuculites poststriatus Emmons, 1842, p. 399, fig. 4.

Nucula poststriata (Emmons). Hall, 1847, p. 151, pl. 34, figs. 2a, b, [?]p. 301, pl. 82, figs. 10a, b.

Cardiomorpha poststriata (Emmons). Emmons, 1855, p. 175, pl. 17, fig. 22.

Lyrodesma poststriatum (Emmons). Billings, 1863, p. 176, figs. 167a, b. Nicholson, 1875, p. 36, fig. 11b. Foerste, 1914a, p. 306. Stewart, 1920, p. 26, pl. 4, fig. 5. Foerste, 1924, p. 169, pl. 25, fig. 10a, b; pl. 43, fig. 9.

[?]*Lyrodesma cannonense* Ulrich, 1894, p. 601, pl. 42, figs. 6-8.

[?]*Lyrodesma schucherti* Ruedemann, 1912, p. 103, pl. 6, fig. 5.

[?]*Lyrodesma poststriatum elongatum* Stewart, 1920, p. 26, pl. 4, fig. 5. Foerste, 1924, p. 170, pl. 22, fig. 8.

Lyrodesma poststriatum manitoulinense Foerste, 1924, p. 170, pl. 43, fig. 5.

DESCRIPTION BASED ON SPECIMENS FROM THE CENTRAL APPALACHIAN UPPER ORDOVICIAN. Shell of medium size, pronounced posterior elongation (median length of 19 specimens, 17 mm; median height, 11 mm). Shape variable, height ranging from 61 to 70 per cent of length (median of 19 measured specimens, 62 per cent). Surface sculpture of fine concentric striae, faint except near edges of valves, about six prominent coarse radial ribs at posterodorsal edge of shell. Prominent schizodont teeth, normally eight; well-marked longitudinal striae on each tooth (Pl. 44, fig. 4); teeth not uniform in size, notable anterior and slight posterior decrease in size away from the umbo. Resilifer absent, ligament area otherwise unknown. Anterior and posterior adductor muscle scars rounded, posterior slightly more elongate. Pedal muscle scars rounded, posterior pedal scar slightly larger and more elongate than anterior. Pallial line with distinct impression of a small pallial sinus, posteroventral, preserved as internal mold on two specimens (Pl. 44, fig. 5); other internal features unknown. Original shell microstructure and mineralogy unknown.

MATERIALS. The description is based on about 30 specimens from central Pennsylvania deposited in the Peabody Museum.

DISCUSSION. Sixteen species and subspecies described from the Middle and Upper Ordovician strata of North America have been assigned to the genus *Lyrodesma* (see Wilson, 1956, p. 64, for a concise generic description). This grouping of species can be informally subdivided into three morphological groups on the basis of shell size, shape variation (height to length ratios) and the degree of posterior expansion. Table 21 outlines these three groups. Stewart (1920, p. 26) also mentioned that there ap-

TABLE 21. An informal morphological grouping of previously defined *Lyrodesma* species. The three groups are qualitative and designed only for a clearer understanding of the shape variability within the central Appalachian Upper Ordovician specimens.

1. Small size, oval, no distinct posterior expansion	2. Medium size, suboval, pronounced posterior expansion	3. Large size, subellipsoidal extreme posterior expansion
Lyrodesma cincinnatiense	*Lyrodesma poststriatum*	*Lyrodesma major*
L. acuminatum	*L. poststriatum elongatum*	*L. postplanum*
L. acuminatum intermedium	*L. poststriatum manitoulinense*	*L. huguesensis*
L. planum	*L. cannonense*	
L. inoratum	*L. schucherti*	
L. conradi		
L. grande		
L. subplanum		

peared to be three distinct subgroups of the genus *Lyrodesma*, based on noticeable differences in height-length ratios; but she did not discuss the distinguishing characteristics of these groups. Instead, she mentioned only a characteristic "type" for each group.

Most of the Appalachian *Lyrodesma* specimens can be assigned to *Lyrodesma poststriatum* of subgroup 2 (Table 21), but a few specimens show morphological characteristics that appear to typify one of the other subgroupings and thus may belong to one or more other species. These latter specimens, because they are rare, have not been described. In fact, the shape variation within the genus itself remains poorly known and a complete resurvey of *Lyrodesma* morphological variability should be undertaken. Thus the three subgroups are not intended as taxonomic groupings in this report, but rather are introduced as a means of emphasizing overall size and shape variability especially with regard to the most common central Appalachian form.

Lyrodesma poststriatum is common in central Pennsylvania, (loc. 122, 37, 35, 52, and 97), where it occurs with *Praenucula levata*, *Ctenodonta*? *pulchella*, crinoids and lesser numbers of *Rafinesquina* "*alternata*" and *Onniella multisecta*. The substratum is a finely laminated silt or mud, and the most likely environmental setting appears to be in quiet, offshore waters. *Lyrodesma* is unique in that it is an Early Paleozoic siphonate bivalve. By analogy with Recent siphonate forms, where depth of burrowing appears directly related to the depth of sinuosity of the pallial sinus, *Lyrodesma* appears to have been a shallow infaunal form. I have also collected a few *Lyrodesma* specimens from localities 189, 192, 195, and 203, where the fauna is dominated by *O. linneyi*, *Ambonychia praecursa* and *Modiolopsis modiolaris* in a muddy silt-sand. These rare specimens of *Lyrodesma* exhibit a more pronounced posterior expansion than the more abundant ones farther north, but unfortunately no pallial lines have been found preserved on these more posteriorly expanded specimens. I suspect, however, that specimens with a more deeply inset pallial sinus might be found, emphasizing a deeper infaunal habit in a more turbulent environment.

LOCALITY REGISTER

(includes only fossiliferous exposures, location given to nearest 0.5 mile.)

Locality	Peabody Museum Number	Description
1	(A-6324)	Road cut 1.0 mile s. of New Tripoli, Pa. along New Tripoli - Lynnville road.
2	(A-6325)	Road cut 1.5 miles n. of Lynnville, Pa. along New Tripoli - Lynnville road.
4	(A-6326)	Road cut 0.5 mile n. of Lynnville, Pa. along New Tripoli - Lynnville road.
9	(A-6327)	Road cut 1.5 miles s. of Pleasant Corners, Pa. along Pleasant Corners - Werley's Corner road.
11	(A-6328)	Road cut less than 0.5 mile s. of loc. 9.
12	(A-6329)	Road cut 0.5 mile s. of loc. 11.
15	(A-6330)	Road cut 1.5 miles w. of loc. 2 and 4 along a paved road leading sw. from New Tripoli, Pa.
16	(A-6331)	Road cut 1.0 mile n. of loc. 15.
17	(A-6332)	Road cut 1.0 mile s. of Lynnport, Pa. along Pa. Rt. 863.
18	(A-6333)	Road cut less than 0.5 mile s. of loc. 17.
19	(A-6334)	Road cut less than 0.5 mile s. of loc. 18.
22	(A-6335)	Road cut less than 0.5 s. of loc. 19.
23	(A-6336)	Road cut a few hundred yards n. of loc. 22.
24	(A-6337)	Road cut a few hundred yards n. of loc. 23.
25	(A-6338)	Road cut 2.0 miles s. of Jacksonville, Pa. along Pa. Rt. 737[?].
26	(A-6339)	Road cut 0.5 mile s. of loc. 25.
27	———	Road cut 1.5 miles w. of Albany, Pa. along Albany - Eckville road.
28	———	Road cut 2.5 miles w. of loc. 27.
30	(A-6340)	Quarry n. of Cedar Springs, Pa., junction Pa. Rts. 64 and 880.
31	(A-6341)	Road cut 1.0 mile se. of Rote, Pa. along Pa. Rt. 880.
32	(A-6342)	Road cut 0.5 mile n. of Loganton, Pa. along Pa. Rt. 880.
33	(A-6343)	Road cut 1.0 mile n. of Carroll, Pa. along Pa. Rt. 880.
34	(A-6344)	Road cut 1.0 mile s. of Rauchtown, Pa. along Pa. Rt. 880.

Locality	Peabody Museum Number	Description
34-A	(A-6345)	Quarry 1.0 mile s. of Rauchtown, Pa. within Pa. State Park grounds a few hundred yards e. of Pa. Rt. 880.
35	(A-6346 to A-6357)	Road cut 2.5 miles s. of Antes Fort, Pa. along Pa. Rt. 44.
36	(A-6358)	Road cut 2.0 miles se. of Collomsville, Pa. along Pa. Rt. 44.
37	(A-6359 to A-6363)	Road cut 0.5 mile n. of Bastress, Pa. along Pa. Rt. 654.
38	(A-6364)	Road cut 1.0 mile s. of Duboistown, Pa. along paved road through north limb of Raccoon Mountain.
39	(A-6365)	Quarry about 2.0 miles s. of Lamar, Pa. immediately n. of Pa. Rt. 780.
39-A	(A-6366)	Road cut a few hundred yards sw. of loc. 39.
42	(A-6369)	Road cut 3.5 miles n. of Livonia, Pa. along Livonia - Greenburr road.
43	(A-6370)	Road cut less than 0.5 mile n. of Livonia, Pa. along Livonia - Greenburr road.
44	(A-6371)	Road cut 0.5 mile n. of Rebersburg, Pa. along Rebersburg - Tylersville road.
45	(A-6372)	Road cut about 5.0 miles e. of Woodward, Pa. along Pa. Rt. 45.
47	(A-6374)	Quarry 1.0 mile s. of Nittany, Pa. along Pa. Rt. 445.
48	(A-6375)	Road cut 1.0 mile s. of junction of Pa. Rt. 192 and north-south paved road, north limb of Brush Mountain.
49	(A-6376)	Road cut 2.0 miles s. of loc. 48, south limb of Brush Mountain.
50	(A-6377)	Road cut 1.0 mile s. of Pleasant Gap, Pa. along Pa. Rt. 53.
51-A	(A-6379)	Road cut less than 0.5 mile n. of Bellefonte, Pa. along Pa. Rt. 53.
52	(A-6380)	Road cut 1.5 miles n. of Jacksonville, Pa. along Pa. Rt. 445.
60	(A-6381)	Quarry at junction of Pa. Rt. 53 and U. S. Rt. 322 at Potters Mill, Pa.
62	(A-6382)	Road cut about 1.0 mile se. of Reedsville, Pa. along U. S. 322.
63	(A-6383)	Road cut about 1.0 mile se. of Reedsville, Pa. along U. S. Rt. 322 Bypass.
64	(A-6384)	Road cut 2.5 miles n. of Belleville, Pa. along Pa. Rt. 305.
68	(A-6388)	Stream cut 1.0 mile nw. of Allensville, Pa.
69	(A-6389)	Road cut 3.5 miles ne. of Mill Creek, Pa. along Pa. Rt. 655.
70	(A-6390)	Road cut 1.0 mile s. of Franklinville, Pa. in Colraine State Park, s. of Pa. Rt. 45.
71	(A-6391)	Two small quarries 1.5 miles ne. of Lemont, Pa. along Lemont - Oak Hill road.
72	(A-6392)	Road cut at Baffalo Run, Pa. along U. S. 322.
73	(A-6393)	Road cut 0.5 mile n. of Centennial, Pa. along Centennial - Port Matilda road.

Locality	Peabody Museum Number	Description
75	(A-6395)	Railroad cut 1.0 mile se. of Tyrone, Pa. a few hundred yards s. of Pa. Rt. 350.
77	(A-6396)	Road cut 3.0 miles n. of Elberta, Pa. along Elberta - Culp road.
77-A	(A-6397)	Road cut a few hundred yards s. of loc. 77.
78	(A-6398)	Railroad cut 0.5 mile s. of Ganister, Pa. a few hundred yards e. of Pa. Rt. 866.
79	(A-6399)	Quarry 0.5 mile nw. of Royer, Pa. a few hundred yards off Pa. Rt. 866.
80	———	Quarry 1.5 miles nw. of Roaring Spring, Pa. along Pa. Rt. 164.
81	(A-6499)	Road cut 2.5 miles w. of Ore Hill, Pa. along Ore Hill - Sproul road.
82	(A-6400)	Road cut at Brumbaugh, Pa. at junction of Pa. Rts. 867 and 869.
83	(A-6401)	Road cut 2.5 miles ne. of Williamsburg, Pa. along Williamsburg - Huntingdon road.
84	(A-6402)	Road cut 2.5 miles se. of Clover Creek, Pa. along Pa. Rt. 164.
86	(A-6403)	Road cut 0.5 mile e. of Loysburg, Pa. along Pa. Rt. 868.
87	(A-6404)	Road cut 4.5 miles s. of Loysburg, Pa. along Pa. Rt. 36.
89	(A-6406)	Road cut a few hundred yards e. of Blue Mountain tunnel entrance, Pa. Turnpike.
91	(A-6407)	Road cut 8.5 miles e. of Tuscarora tunnel entrance, Pa. Turnpike.
92	(A-6408)	Road cut about 2.0 miles e. of Bedford, Pa., Pa. Turnpike.
93	(A-6409)	Road cut at junction of two unmarked, paved roads a few hundred yards e. of Sulfur Springs, Pa., western limb of Wills Mountain.
94	(A-6410)	Road cut 1.5 miles e. of Buffalo Mills, Pa., Buffalo Mountain.
95	(A-6411)	Road cut 2.0 miles n. of Fossilville, Pa. along unpaved road through southern edge of Buffalo Mountain.
96	(A-6412)	Road cut 2.0 miles e. of Bedford, Pa. along U. S. Rt. 30; a few hundred yards w. of junction of U. S. 30 and Pa. Rt. 326.
97	(A-6413)	Road cut 1.5 miles s. of Rainesburg, Pa. along unpaved Pa. Rt. 326.
98	(A-6414)	Road cut 6.5 miles s. of Loysburg, Pa. along Pa. Rt. 36.
99	(A-6415)	Road cut 1.0 mile w. of Everett, Pa., a few hundred yards off U. S. 30 on paved service road.
100	(A-6416)	Road cut 1.5 miles w. of Everett, Pa. along Everett - Ashcom road.
101	(A-6417)	Road cut 2.5 miles se. of McConnellsburg, Pa. along Pa. Rt. 16.
102	(A-6418)	Quarry 0.5 mile ne. of Knobsville, Pa. near junction of narrow, paved unmarked road and U. S. 522.

Locality	Peabody Museum Number	Description
103	(A-6419)	Road cut 3.0 miles e. of McConnellsburg, Pa. along U. S. 30.
104	(A-6420)	Road cut 2.0 miles w. of Fort Louden, Pa. along U. S. 30.
105	(A-6500)	Road cut 1.5 miles e. of Fannetsburg, Pa. along Fannetsburg - Upper Strasburg road.
106	(A-6421)	Road cut 1.5 miles w. of Upper Strasburg, Pa. along Pa. Rt. 533[?].
107	(A-6422)	Road cut 1.5 miles w. of Roxbury, Pa. along Pa. Rt. 641.
108	(A-6423)	Road cut 7.0 miles w. of Roxbury, Pa. along Pa. Rt. 641.
109	(A-6424)	Quarry 2.0 miles s. of Spring Run, Pa. along Pa. Rt. 641 immediately n. of Pa. Turnpike overpass.
110	(A-6425)	Road cut 4.5 miles e. of Neelytown, Pa. along Pa. Rt. 641.
111	(A-6426)	Road cut 2.0 miles e. of Orbisonia, Pa. along paved, unmarked road immediately n. of junction with U. S. 522.
112	(A-6427)	Road cut 2.0 miles w. of Mt. Union, Pa. along U. S. 22.
120	(A-6428)	Road cut 8.0 miles n. of Lemoyne, Pa. along U. S. 11 and 15.
121	(A-6429)	Road cut 1.5 miles n. of Doubling Gap, Pa. along Pa. Rt. 233.
122	(A-6430)	Road cut 3.0 miles e. of East Waterford, Pa. along partially paved East Waterford - New German Town road.
123	(A-6431)	Road cut 4.5 miles n. of Doylesburg, Pa. along Pa. Rt. 274.
124	(A-6432)	Road cut 4.5 miles n. of Clear Spring, Md., near Hanging Rock, Bear Pond Mountains.
125	(A-6433)	Road cut 1.5 miles e. of Thorn Hill, Tenn. along U. S. 255.
126	(A-6434)	Road cut 3.0 miles w. of Joppa, Tenn. along Joppa - Powder Springs road, Clinch Mountain.
127	(A-6435)	Road cut 1.5 miles s. of Rose Hill, Tenn. along Tenn. Rt. 33.
128	(A-6436)	Road cut 2.0 miles w. of Ridenour, Tenn. along Tenn. Rt. 61, Lone Mt.
129	(A-6437)	Road cut and stream cut 3.0 miles nw. of Yoakum Crossroad, Tenn. along unpaved road across Powell Valley and eastern edge of Cumberland Mountain; road parallels Davis Creek.
130	(A-6438)	Road cut and railroad cut 2.0 miles n. of Arthur, Tenn. along unpaved Arthur - Cumberland Gap road.
131	(A-6439)	Road cut immediately s. of Cumberland Gap, Tenn. along motel service road parallel to Tenn. Rt. 32 and U. S. 25E.
132	(A-6440)	Road cut 2.5 miles w. of Sycamore Hall, Tenn. along unpaved road from Sycamore Hall through Wallen Ridge that junctions with unmarked paved road 2.0 miles n. of Tazwell, Tenn.
133	(A-6441)	Road cut 2.0 miles sw. of Klondike, Tenn. along Tenn. Rt. 66.
134	(A-6442)	Road cut 2.0 miles nw. of Choptack, Tenn. along Tenn. Rt. 66.
135	(A-6443)	Road cut 7.0 miles se. of Kyles Ford, Tenn. along Tenn. Rt. 70, Clinch Mountain.

Locality	Peabody Museum Number	Description
136	(A-6501)	Road cut 0.5 mile s. of Unthanks, Va. along Va. Secondary Rt. 758.
137	(A-6444)	Road cut 1.0 mile w. of U. S. 58 near Hagan, Va. along the Hagan - Smiley road.
138	(A-6445)	Road cut 3.5 miles se. of Bowling, Va. along Va. Primary Rt. 70 and U. S. Alt. 58.
139	(A-6446)	Road cut 2.5 miles nw. of Blackwater, Va. along Va. Primary Rt. 70 and 798[?], Powell Mountain.
140	(A-6447)	Road cut 3.0 miles n. of Mendota, Va. along unpaved Mendota - Collinwood, Va. road.
141	(A-6448)	Road cut 3.5 miles nw. of Pattonsville, Va. along U. S. 421 and 58, Powell Mountain.
142	(A-6449)	Road cut 1.5 miles nw. of Stickleyville, Va. along U. S. 421 and 58, Wallen Ridge.
143	(A-6450)	Stream cut 1.0 mile nw. of Pennington Gap, Va. a few hundred yards ne. of U. S. 421.
144	(A-6451)	Road cut 1.5 miles se. of Olinger, Va. along paved, unmarked road that junctions with U. S. Alt. 58.
145	(A-6452)	Road cut 1.0 mile s. of Rockdell, Va. along Va. Primary Rt. 80, Clinch Mountain.
147	(A-6453)	Road cut 1.5 miles se. of Mt. Gate, Va. along Va. Primary Rt. 16, Clinch Mountain.
148	(A-6454)	Road cut 12.5 miles n. of Marion, Va. along Va. Primary Rt. 16, Walker Mountain.
149	(A-6455)	Road cut about 10 miles n. of Broadford, Va. along unpaved Va. Primary Rt. 91, Clinch Mountain.
150	(A-6456)	Road cut 6.0 miles nw. of Chilhowie, Va. along Va. Primary Rt. 107, Walker Mountain.
151	(A-6457)	Road cut a few hundred yards s. of Walker Mountain lookout tower along Va. Secondary Rt. 621, near junction with U. S. 21 and 52.
152	(A-6458)	Road cut 1.5 miles s. of Rocky Gap, Va. along U. S. 21 and 52, Wolf Creek Mountain.
153	(A-6459)	Road cut 2.0 miles se. of Bluefield, W. Va. along U. S. 21 and 52, East River Mountain.
160	(A-6460)	Road cut about 10 miles s. of Wardensville, W. Va. along unpaved road parallel to Waites Run, Great North Mountain.
161	(A-6461)	Road cut 3.0 miles e. of Lost City, W. Va. along W. Va. Rt. 59, Great North Mountain.
162	(A-6462)	Road cut 4.0 miles n. of Liberty Furnace, Va. along unpaved Liberty Furnace - Perry road.
163	(A-6463)	Road cut 1.0 mile w. of Cootes Store along Va. Primary Rt. 259 (Brock's Gap).
164	(A-6464)	Road cut about 15 miles w. of Harrisonburg, Va. at Harrison's Gap, along Harrisonburg - Fulks Run road.

Locality	Peabody Museum Number	Description
165	(A-6465)	Road cut 0.5 mile w. of Basore, W. Va. along Basore - Mathias road.
166	(A-6466)	Road cut about 13 miles e. of Wardensville, W. Va. along Va. Primary Route 55, eastern limb of Great North Mountain.
167	(A-6467)	Road cut 3.0 miles s. of Water Lick, Va. along Va. Secondary Rt. 678, Massanutten Mountain.
168	(A-6468)	Road cut about 8 miles e. of New Market, Va. along U. S. 211 (New Market Gap).
169	(A-6469)	Road cut about 9 miles nw. of Shenandoah, Va. along unpaved road, eastern part of Massanutten Mountain.
170	(A-6470)	Road cut and railroad cut at Buffalo Gap, Va. along Va. Primary Rt. 254, Little North Mountain.
171	(A-6471)	Road cut 1.5 miles w. of McKinley, Va. along unpaved McKinley - Craigsville road.
172	(A-6472)	Road cut 7.0 miles nw. of Kerrs Creek, Va. along U. S. 60.
173	(A-6473)	Road cut 5.0 miles e. of junction of U. S. 60 and Va. Secondary Rt. 770, along Va. Secondary Rt. 770, North Mountain.
174	(A-6474)	Road cut 0.5 mile nw. of Eagle Rock, Va. along U. S. 220 e. of the James River.
175	(A-6475)	Road cut 0.5 mile sw. of Eagle Rock, Va. along U. S. 220 w. of the James River.
177	(A-6476)	Road cut 2.0 miles e. of Catawba, Va. along Va. Primary Rt. 311, Catawba Mountain.
178	(A-6477)	Road cut 2.5 miles sw. of Fagg, Va. along Va. Secondary Rt. 603.
179	(A-6478)	Road cut 3.0 miles s. of Radford, Va. along Va. Secondary Rt. 787, Ingle Mountain.
180	(A-6479)	Road cut 2.0 miles s. of Poplar Hill, Va. along Va. Primary Rt. 100, Walker Mountain.
181	(A-6480)	Road cut 5.5 miles s. of Mechanicsburg, Va. along Va. Secondary Rt. 738, Walker Mountain.
182	(A-6481)	Road cut 3.0 miles s. of Burkes Garden, Va. along Va. Secondary Rt. 623, southeastern limb of Garden Mountain.
183	(A-6482)	Road cut at Gose Mill, Va. along Va. Secondary Rt. 623, northwestern limb of Garden Mountain.
184	(A-6483)	Road cut 1.0 mile s. of Gratton, Va. along Va. Secondary Rt. 623, Rich Mountain.
185	(A-6484)	Railroad cut 1.0 mile n. of McCoy, Va. along Va. Secondary Rt. 652, Walker - Gap Mountain.
186	(A-6323)	Road cut 2.5 miles n. of Narrows, Va. along U. S. 460, East River Mountain.
187	(A-6485)	Road cut 1.5 miles n. of Mountain Lake, Va. along Va. Secondary Rt. 700, between Salt Pond and Doe Mountains.
188	(A-6486)	Road cut 3.5 miles s. of New Castle, Va. along Va. Primary Rt. 42.

Locality	Peabody Museum Number	Description
189	(A-6487)	Road cut 4.0 miles s. of Paint Bank, Va. along Va. Primary Rt. 311, southern limb of Little Mountain.
190	(A-6322)	Road cut 2.0 miles s. of Sweet Springs, W. Va. along Va. Primary Rt. 311, Peters Mountain.
191	(A-6488)	Road cut 0.5 mile se. of Cliffdale, Va. along Va. Secondary Rt. 616.
192	(A-6489)	Road cut 11.0 miles nw. of Eagle Rock, Va. along Va. Secondary Rt. 621 (or 613[?]), Rich Patch Mountain.
193	(A-6490)	Road cut 4.5 miles se. of Falling Spring, Va. along U. S. 220, Little Mountain.
194	(A-6491)	Road cut at Hot Springs, Va. paved road sw. of railroad station to Bacova Junction.
195	(A-6492)	Road cut 1.5 miles e. of junction of U. S. 220 and Va. Primary Rt. 39 along Va. Primary Rt. 39 e. of Warm Springs, Va.
196	(A-6493)	Road cut 2.0 miles n. of junction of U. S. 220 and Va. Primary Rt. 39 along U. S. 220 n. of Warm Springs, Va.
197	(A-6494)	Road cut 0.5 mile w. of Warm Springs, Va. along Va. Primary Rt. 39.
199	(A-6495)	Road cut 2.0 miles w. of Vanderpool, Va. along Va. Primary Rt. 84, Back Creek Mountain.
200	(A-6496)	Road cut 0.5 mile w. of Trimble, Va. along Trimble - Mustoe road, Jack Mountain.
201	(A-6497)	Road cut 2.5 miles e. of Hightown, Va. along U. S. 250.
202	(A-6498)	Road cut 1.0 mile w. of Hightown, Va. along U. S. 250.
203	(A-6301 to A-6321)	Road cut about 12 miles w. of Franklin, W. Va. along U. S. 33, eastern limb of North Fork Mountain.
204	———	Road cut 1.5 miles w. of loc. 203, west limb of North Fork Mountain.
205	———	Gas line cut 1.5 miles e. of Mouth of Seneca, W. Va.
206	———	Road cut 2.0 miles w. of Saumsville, Va. along Va. Secondary Rt. 600.
207	———	Quarry 2.0 miles n. of Lickdale, Pa. along Pa. Rt. 72 (Swatara Gap).

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PLATES

Abbreviations used in explanations:

YPM — Peabody Museum of Natural History,
Yale University, New Haven, Connecticut
Loc. — Locality

All illustrated specimens are deposited in the Peabody Museum of Natural History and were collected for this study. All magnifications are given in linear dimensions.

PLATE 1

(×5)

A-6304 — Disrupted laminae presumably due to biogenic reworking, phosphate grains seen as subround dark clasts—Locality 203. Section cut about 70 feet below Oswego–Reedsville contact.

PLATE 2

(×0.67)

A-6304 — Bedding plane with abundant *Ambonychia praecursa* and a few *Modiolopsis modiolaris* essentially "in place" and forming a small, clustered mussel-like bank. Viewed from underside of bedding plane. YPM 26065 — Locality 203.

PLATE 3

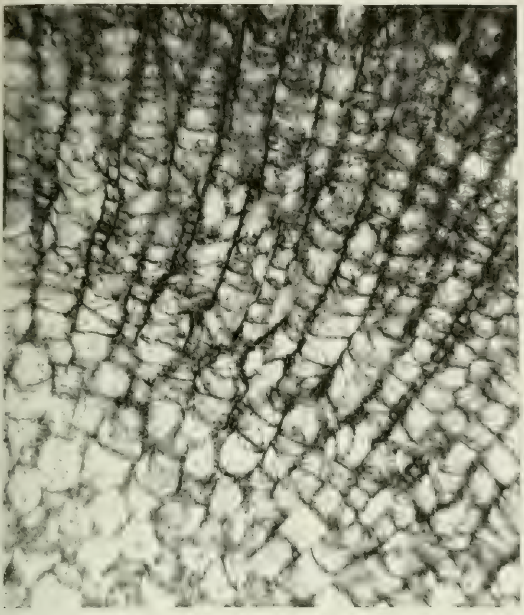
All figures are ×30 except fig. 3 (×50).

Figs. 1-3. Genus *Monticulipora* ....p. 70

1. YPM 25848, Loc. 141 (A-6448), transverse section.
2. YPM 25849, Loc. 141 (A-6448), longitudinal section.
3. YPM 25848, Loc. 141 (A-6448), longitudinal section, same specimen as fig. 1.

Fig. 4. Genus *Dekayia* ....p. 71

4. YPM 25850, Loc. 128 (A-6436), longitudinal section.



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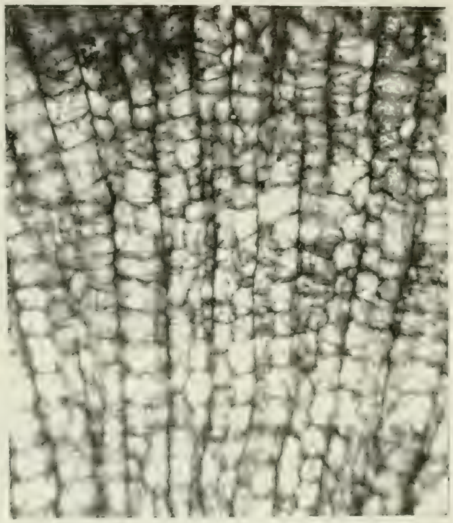

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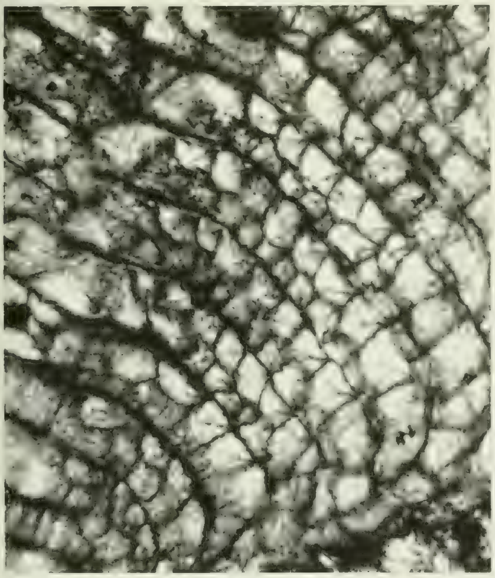

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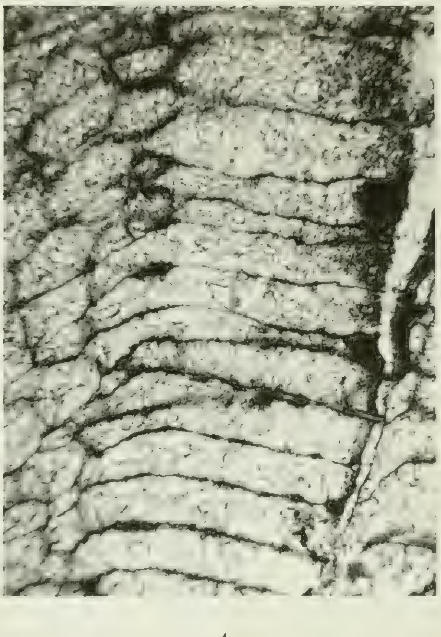

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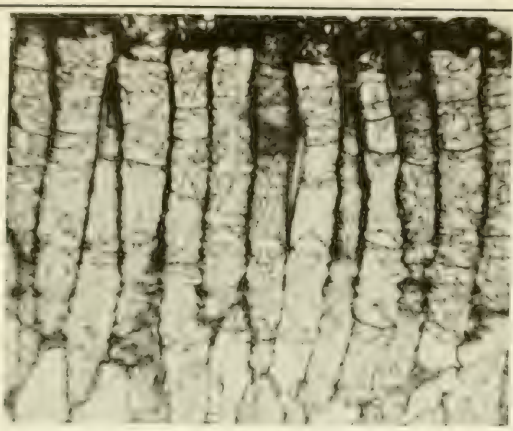

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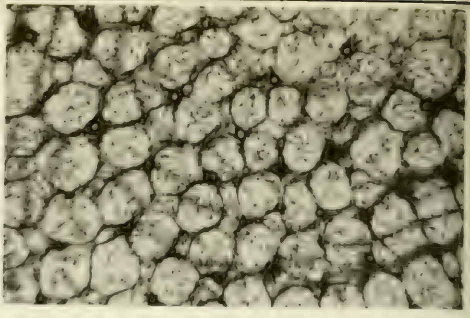

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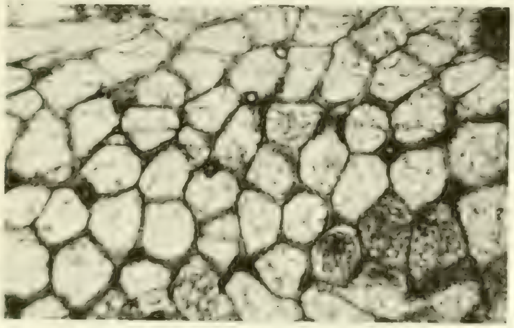

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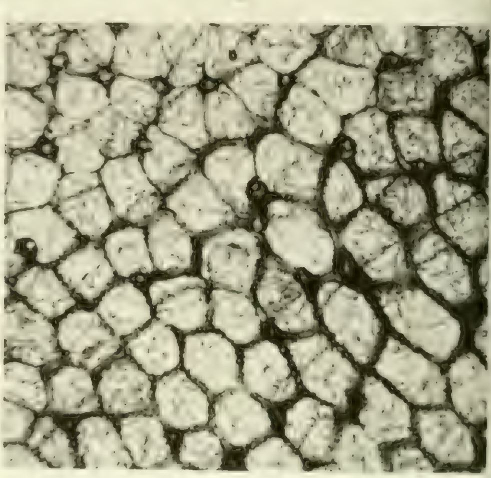

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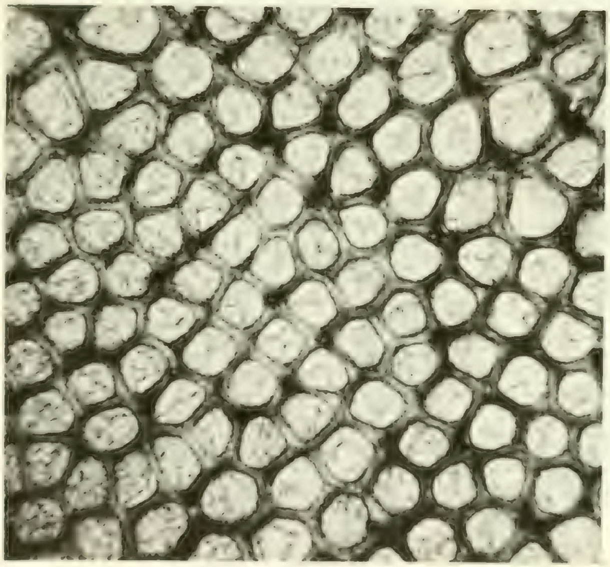

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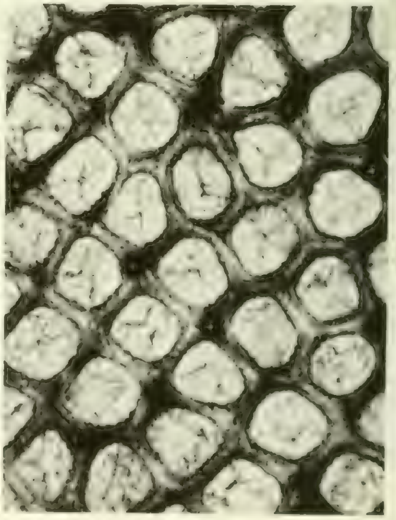

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PLATE 4

All figures are ×30 except fig. 6 (×50).

Figs. 1-6. Genus *Dekayia* .... p. 71

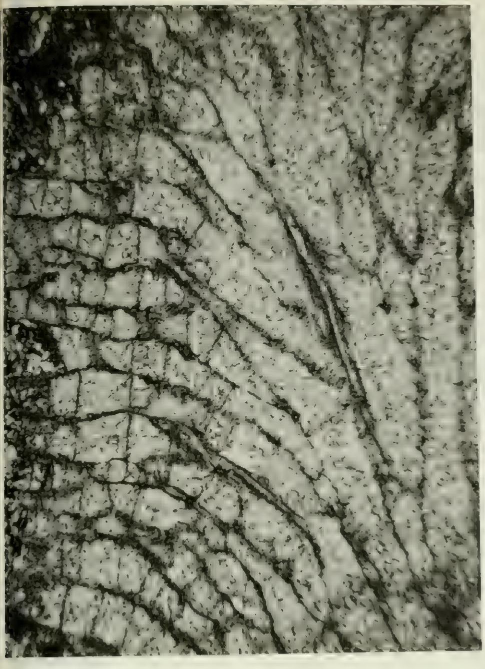
1. YPM 25854, Loc. 203 (A-6304), longitudinal section.
2. YPM 25852, Loc. 132 (A-6440), tangential section.
3. YPM 25850, Loc. 128 (A-6436), tangential section, same specimen as pl. 3, fig. 4.
4. YPM 25851, Loc. 203 (A-6304), tangential section.
5. YPM 25853, Loc. 126 (A-6434), tangential section.
6. YPM 25853, similar to fig. 5 only higher magnification.

PLATE 5

All figures ×30.

Figs. 1-4. Genus *Dekayia* . . . . p. 71

1. YPM 25852, Loc. 132 (A-6440), longitudinal section, same specimen as pl. 4, fig. 2.
2. YPM 25851, Loc. 203 (A-6304), longitudinal section, same specimen as pl. 4, fig. 4.
3. YPM 25855, Loc. 203 (A-6302), longitudinal section.
4. YPM 25856, Loc. 128 (A-6436), longitudinal section.



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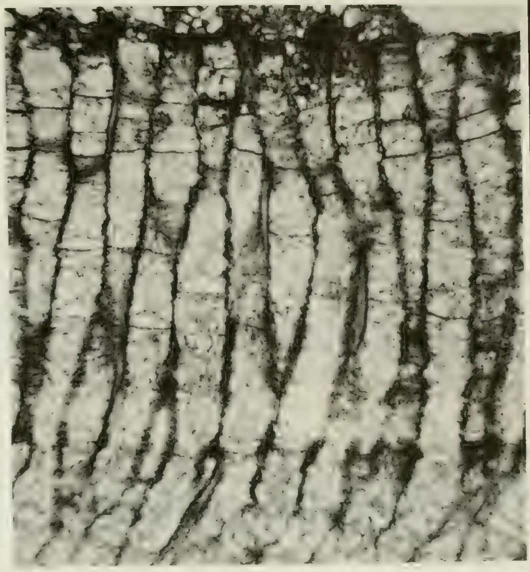

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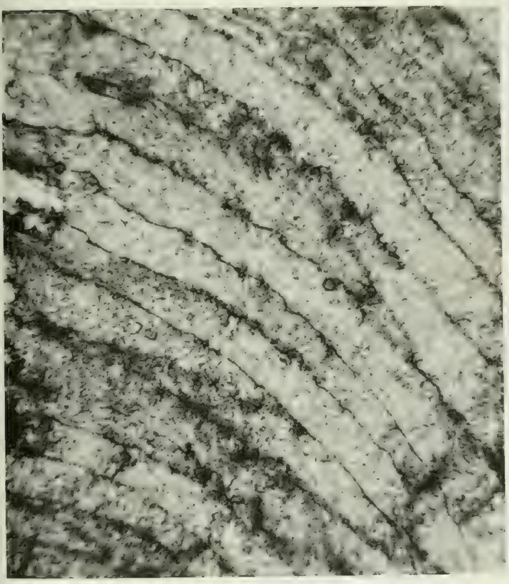

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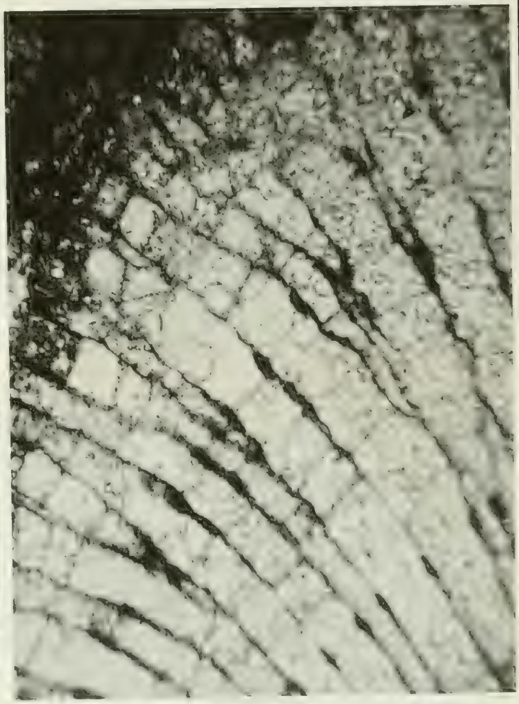

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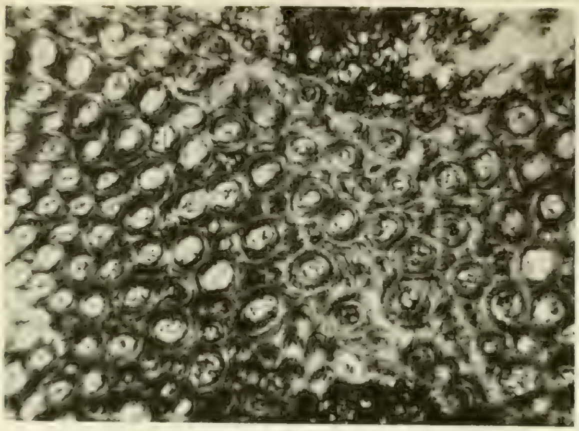

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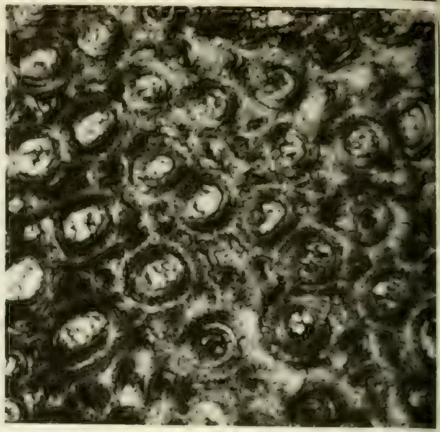

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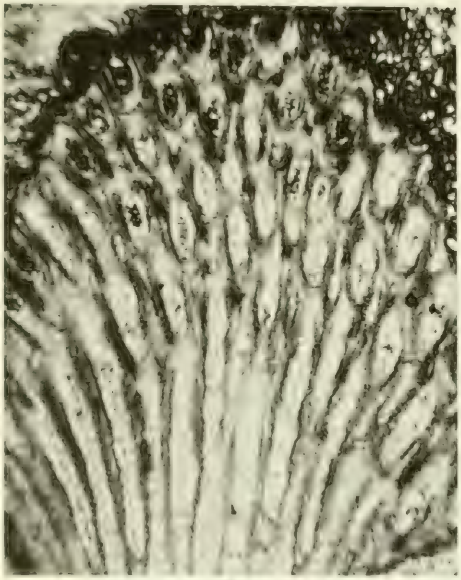

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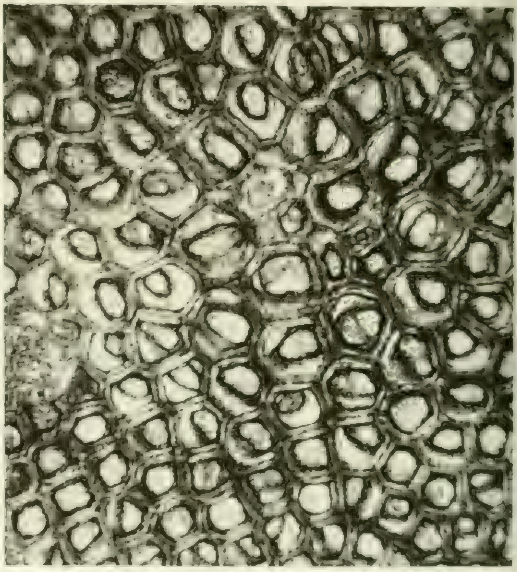

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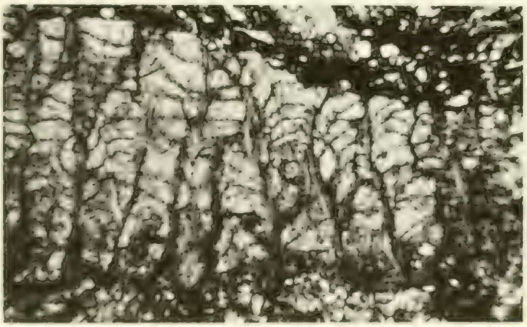

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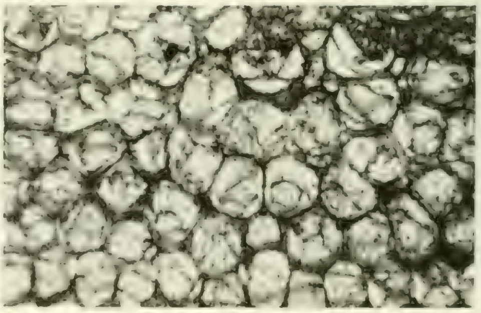

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PLATE 6

All figures are ×30 except fig. 2 (×50).

Figs. 1-3. Genus *Batostomella* ....p. 73

1. YPM 25857, Loc. 126 (A-6434), tangential section.
2. YPM 25857, similar to fig. 1 only higher magnification.
3. YPM 25857, Loc. 126 (A-6434), longitudinal section, growing tip, same specimen as fig. 1.

Figs. 4-5. Genus *Peronopora* ....p. 74

4. YPM 25858, Loc. 140 (A-6447), tangential.
5. YPM 25859, Loc. 125 (A-6443), longitudinal section.

Fig. 6. Probable Genus *Peronopora* ....p. 74

6. YPM 25860, Loc. 141 (A-6448), tangential section.

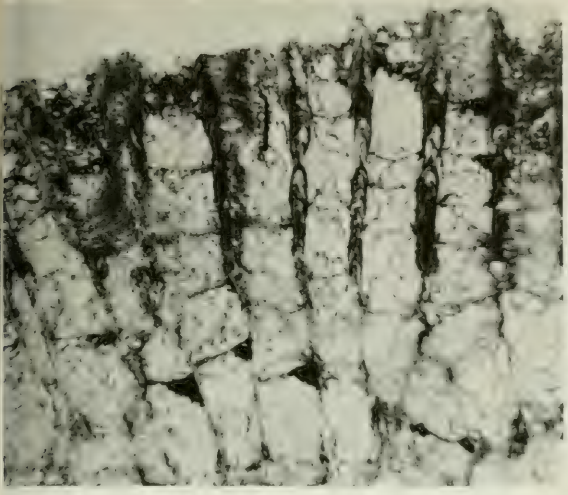
PLATE 7

All figures are ×30 except fig. 1 (×50).

Figs. 1-2. Genus *Heterotrypa* ....p. 74
  1. YPM 25861, Loc. 140 (A-6447), transverse section.
  2. YPM 25862, Loc. 125 (A-6433), longitudinal? section of small fragmentary specimen.

Figs. 3, 5. Genus *Amplexopora* ....p. 74
  3. YPM 25863, Loc. 131 (A-6439), transverse section.
  5. YPM 25863, Loc. 131 (A-6439), tangential section, same specimen as figure 3.

Figs. 4, 6. Probable Genus *Amplexopora* ....p. 74
  4. YPM 25864, Loc. 141 (A-6448), transverse section.
  6. YPM 25865, Loc. 141 (A-6448), longitudinal section.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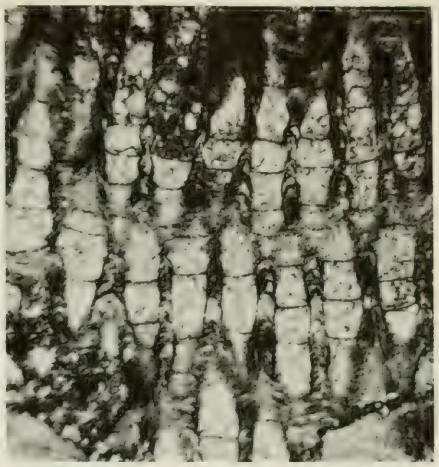
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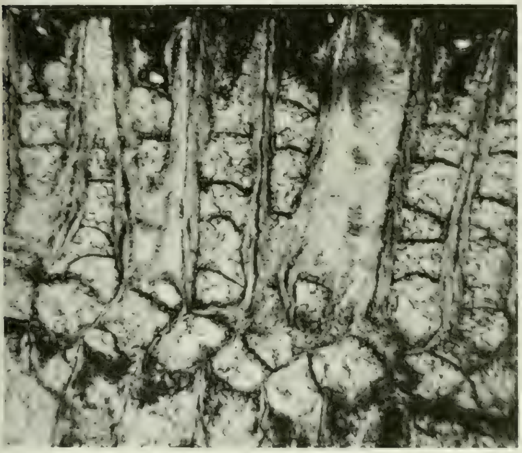
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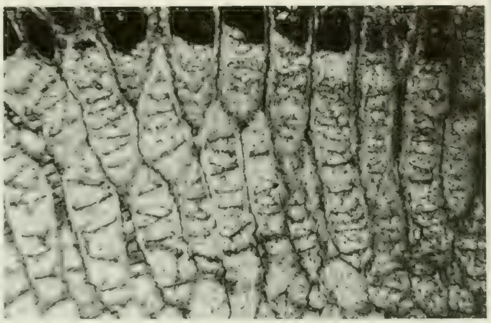
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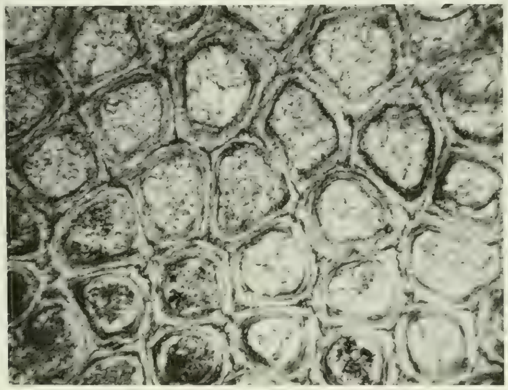
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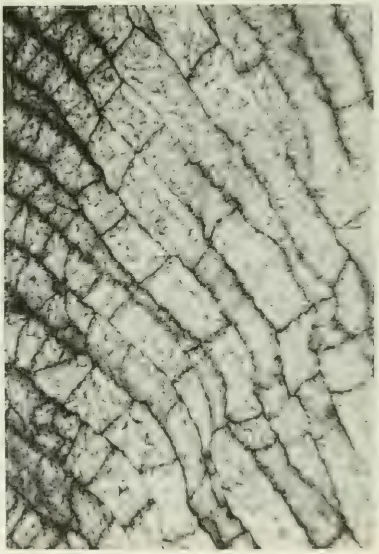
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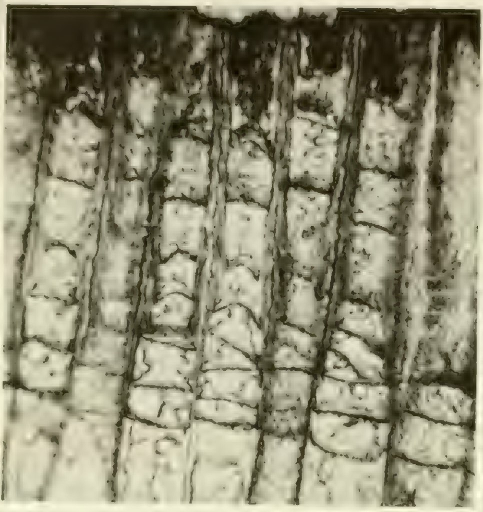

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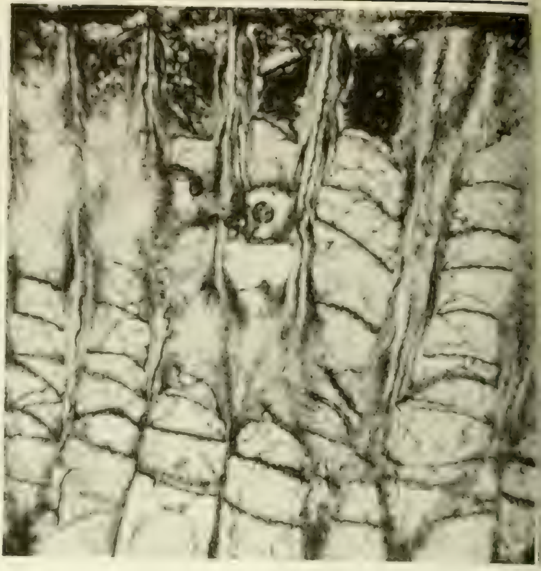

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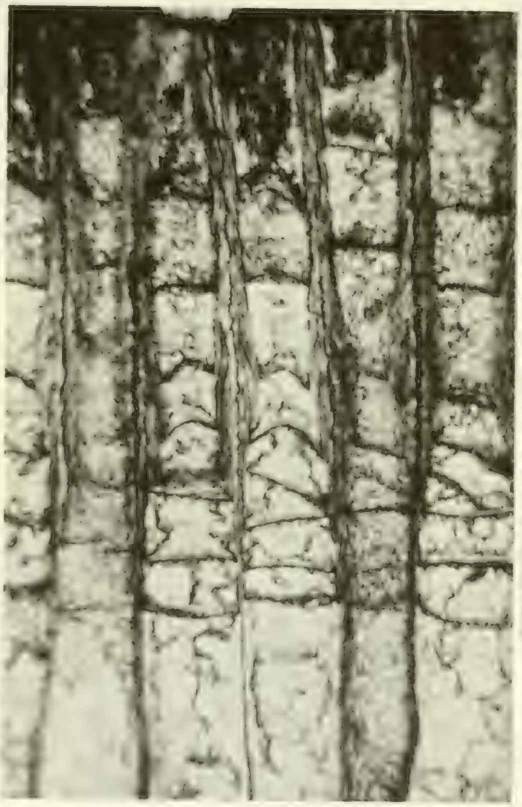

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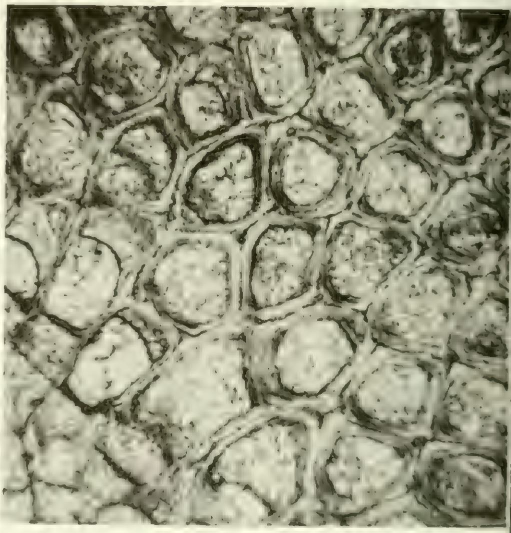

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PLATE 8

All figures are ×30 except fig. 3 (×50)

Figs. 1-4. Genus *Amplexopora* . . . . p. 74

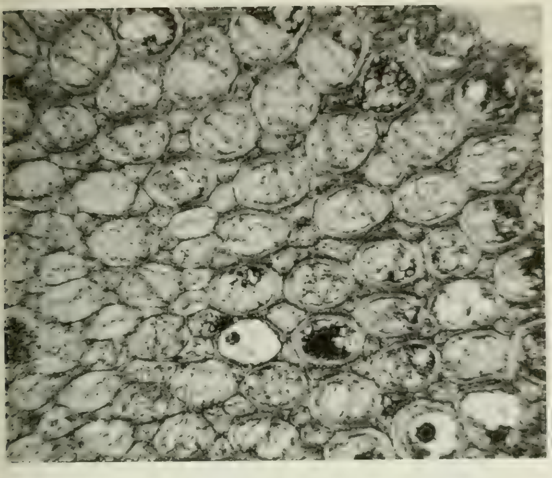
1. YPM 25866, Loc. 131 (A-6439), longitudinal section.
2. YPM 25866, Loc. 131 (A-6439), longitudinal section, same specimen as fig. 1.
3. YPM 25866, similar to fig. 1 only higher magnification.
4. YPM 25863, Loc. 131 (A-6439), tangential section, same specimen as pl. 7, fig. 3.

PLATE 9

All figures are ×30 except fig. 5 (×50).

Figs. 1-6. Genus *Hallopora* .... p. 75

1. YPM 25867, Loc. 127 (A-6435), tangential section.
2. YPM 25868, Loc. 34-A (A-6345), tangential section.
3. YPM 25869, Loc. 147 (A-6453), longitudinal section.
4. YPM 25867, Loc. 127 (A-6435), longitudinal section, same specimen as fig. 1.
5. YPM 25870, Loc. 34-A (A-6345), transverse section.
6. YPM 25871, Loc. 147 (A-6453), tangential section.



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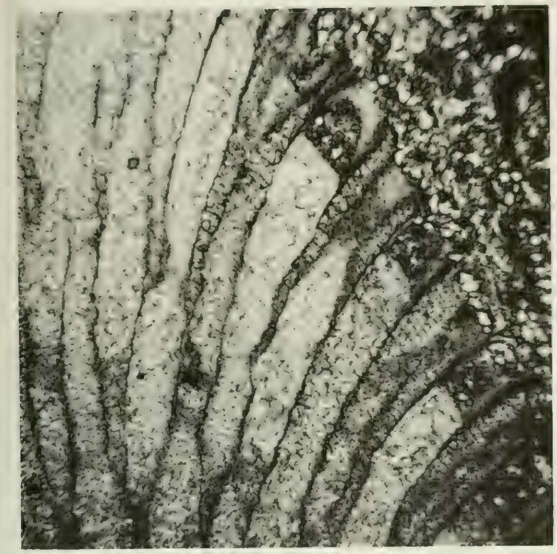

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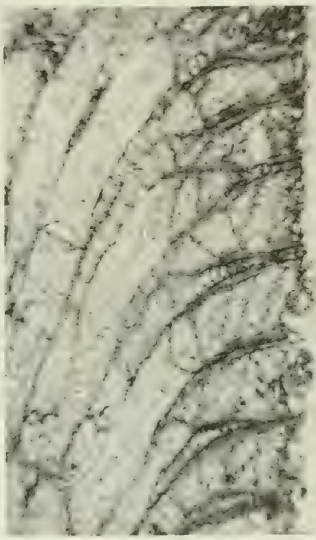

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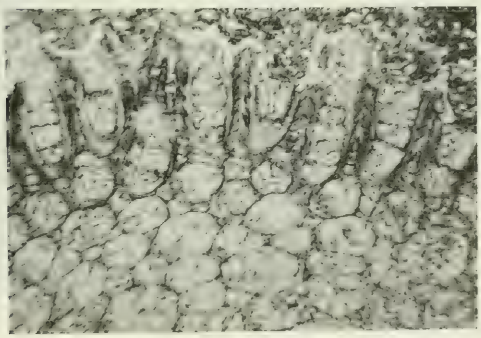

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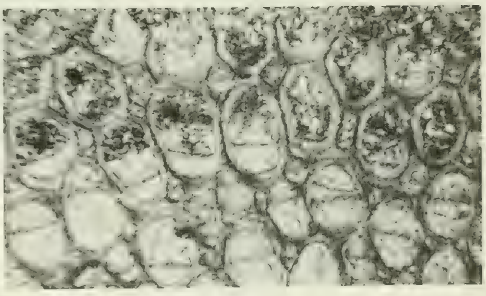

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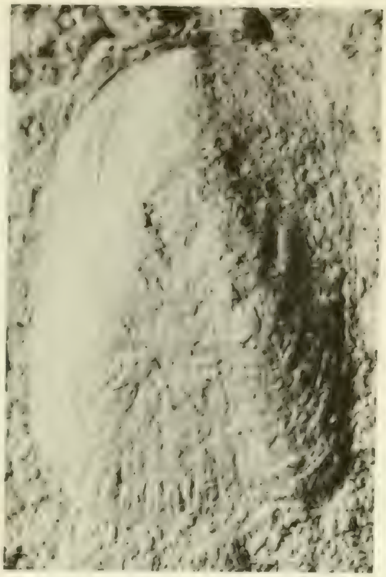

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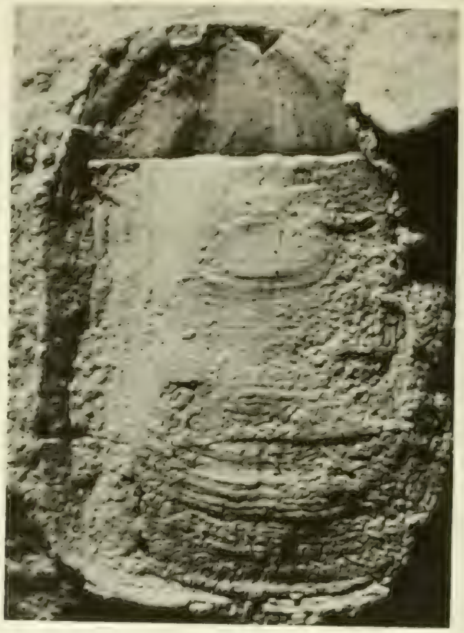

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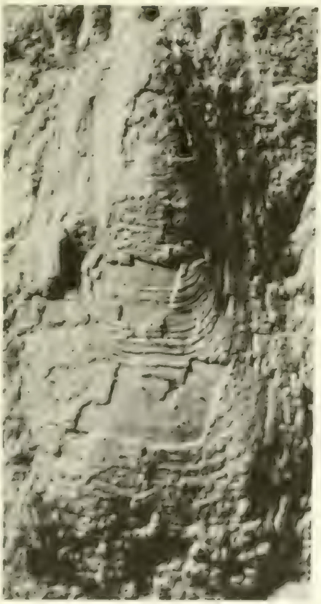

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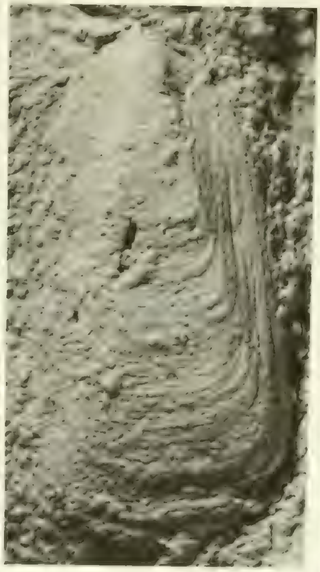

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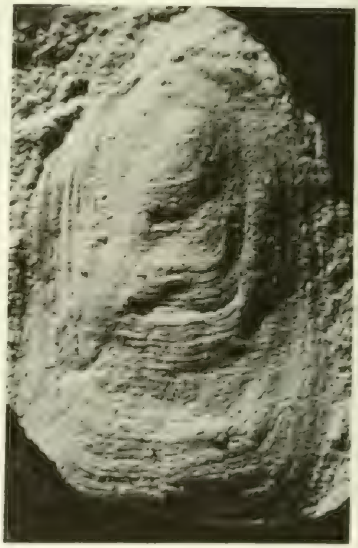

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PLATE 10

All figures are ×4.

Figs. 1-5. Genus *Lingula*? . . . . p. 76

1. YPM 25872, Loc. 98 (A-6414).
2. YPM 25873, Loc. 203 (A-6309).
3. YPM 25874, Loc. 179 (A-6478).
4. YPM 25875, Loc. 203 (A-6314).
5. YPM 25876, Loc. 203 (A-6309).

PLATE 11

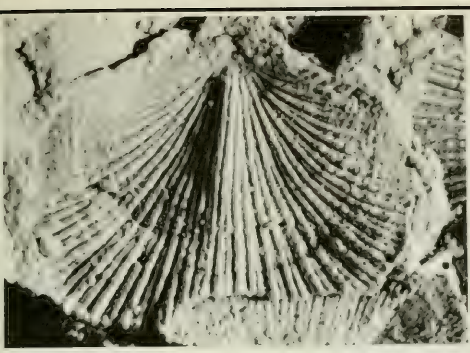
All figures are ×4 except figs. 7, 8 (×2).

Figs. 1-6. *Onniella multisecta* (Meek) ....p. 82

1. YPM 25877, Loc. 35 (G) (A-6352), brachial valve external. Image reversed.
2. YPM 25878, Loc. 39 (A-6365), pedicle valve internal, latex impression of fig. 5, showing large hinge teeth and deeply impressed crural fossettes.
3. YPM 25879, Loc. 35 (B) (A-6347), brachial valve internal, latex impression of fig. 4.
4. YPM 25879, Loc. 35 (B) (A-6347), brachial valve internal mold (natural).
5. YPM 25878, Loc. 39 (A-6365), pedicle valve internal mold (natural).
6. YPM 25880, Loc. 39 (A-6365), brachial valve internal mold (natural).

Figs. 7-8. *Hebertella sinuata* (Hall) ....p. 78

7. YPM 25881, Loc. 147 (A-6453), pedicle valve internal mold (natural).
8. YPM 25882, Loc. 147 (A-6453), brachial valve internal mold (natural).



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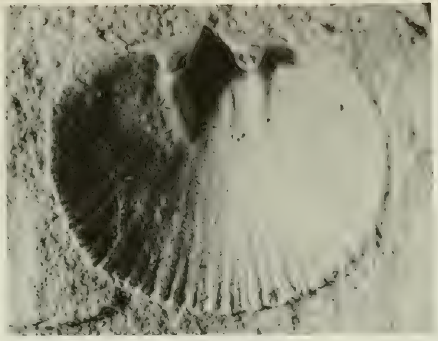

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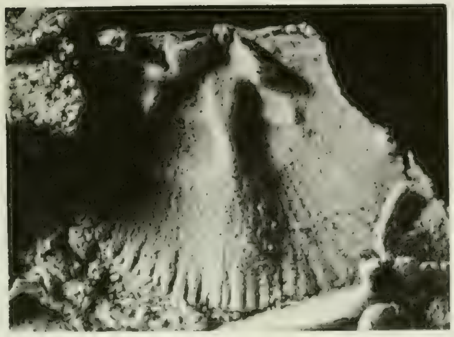

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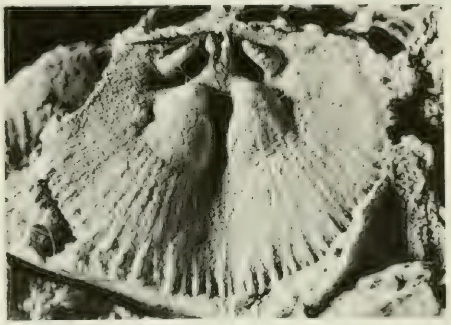

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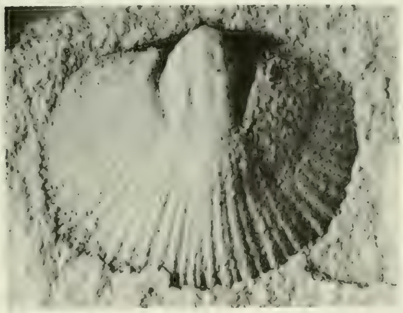

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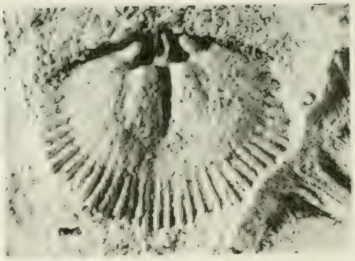

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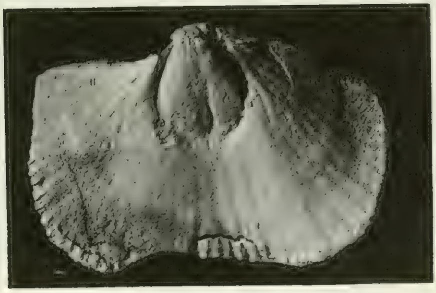

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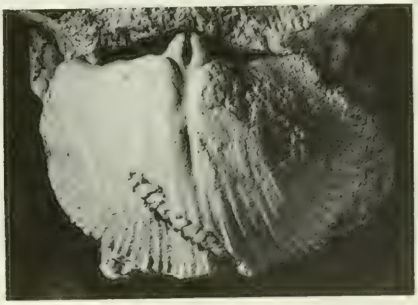

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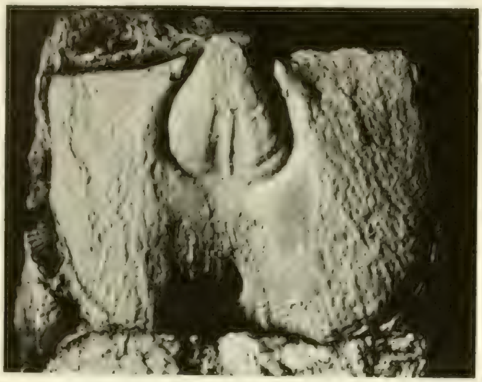

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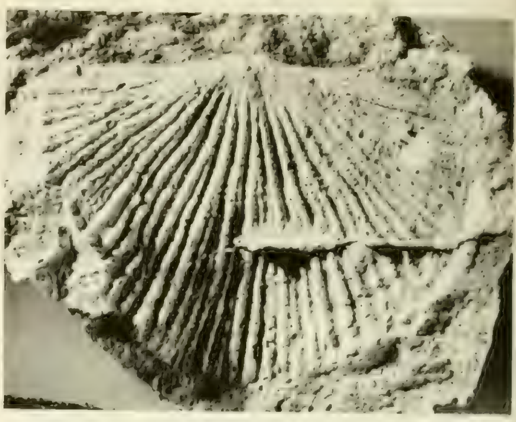

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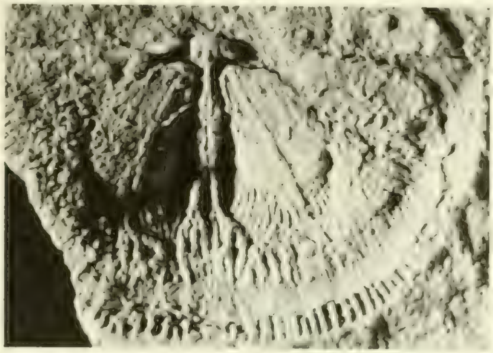

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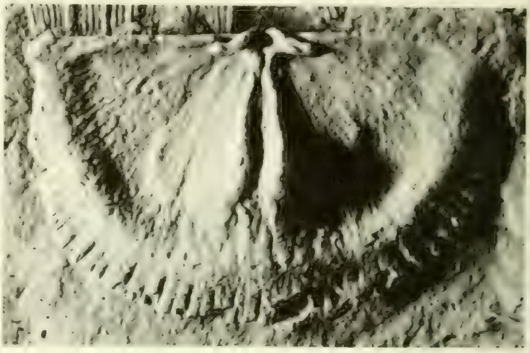

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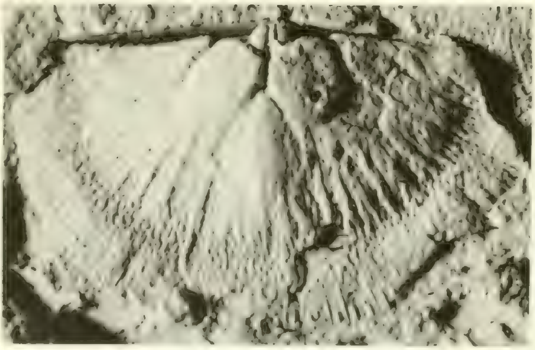

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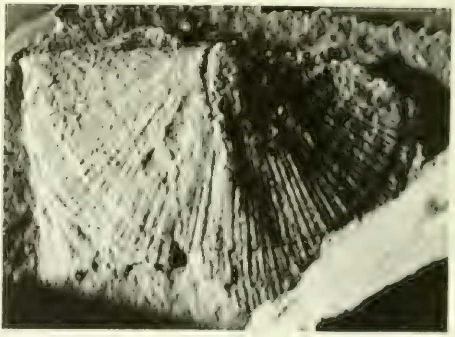

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PLATE 12

All figures are ×4 except figs. 1, 2 (×2).

Fig. 1. *Hebertella sinuata* (Hall) ....p. 78

1. YPM 25883, Loc. 147 (A-6453), pedicle valve internal mold (natural).

Fig. 2. Probable *Hebertella sinuata* (Hall) ....p. 78

2. YPM 25884, Loc. 15 (A-6330), ?brachial valve external, latex impression.

Figs. 3-6. *Sowerbyella* (*Sowerbyella*) *sericea* (Hall) ....p. 85

3. YPM 25885, Loc. 31 (A-6341), brachial valve internal mold (natural).
4. YPM 25886, Loc. 31 (A-6341), brachial valve internal, latex impression showing well-defined submedial septa and curved crural bases.
5. YPM 25887, Loc. 31 (A-6341), pedicle valve internal mold (natural) showing well-defined ventral muscle scars.
6. YPM 25888, Loc. 31 (A-6341), pedicle valve external, latex impression.

PLATE 13

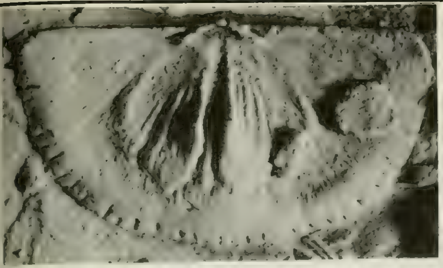
Figures 1-4 (×4), Figures 5-8 (×2).

Figs. 1-4. *Sowerbyella* (*Sowerbyella*) *sericea* (Hall) ....p. 85

1. YPM 25889, Loc. 31 (A-6341), brachial valve internal, latex impression showing flat-lying submedial septa flanking median septum. Lighting from lower right.
2. YPM 25890, Loc. 31 (A-6341), pedicle valve internal mold (natural) showing well-defined ventral muscle scars.
3. YPM 25891, Loc. 31 (A-6341), brachial valve external.
4. YPM 25892, Loc. 31 (A-6341), brachial valve internal mold (natural).

Figs. 5-8. *Orthorhynchula linneyi* (James) ....p. 91

5. YPM 25893, Loc. 203 (A-6303), brachial valve up.
6. YPM 25894, Loc. 203 (A-6307), posterior internal latex impression showing prominent crura in brachial valve; impression of fig. 7.
7. YPM 25894, Loc. 203 (A-6307), internal mold (natural), umbo very prominent.
8. YPM 25895, Loc. 203 (A-6306), internal mold (natural).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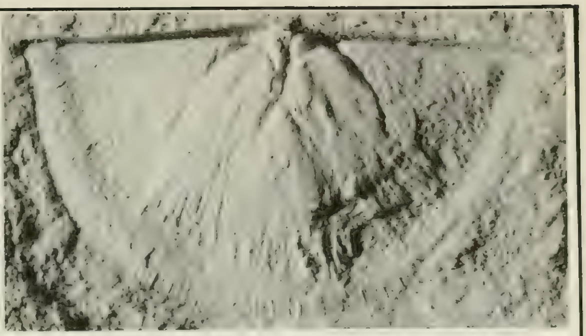
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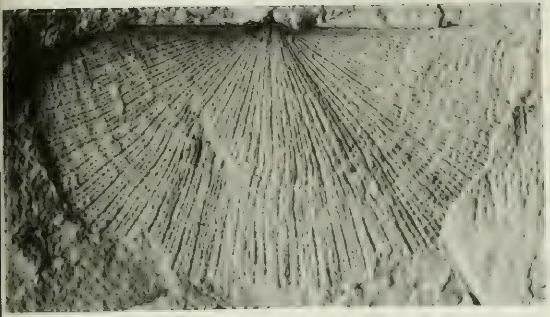
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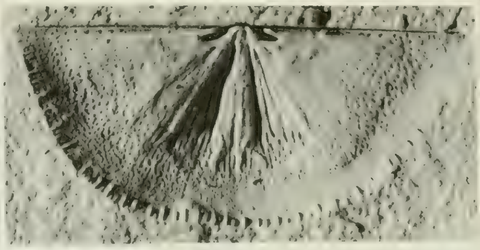
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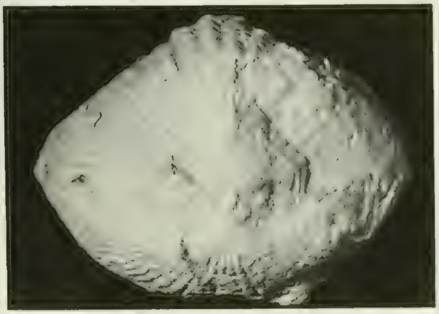
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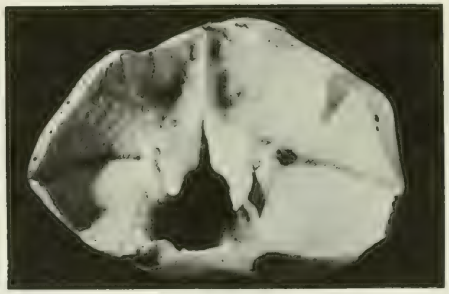
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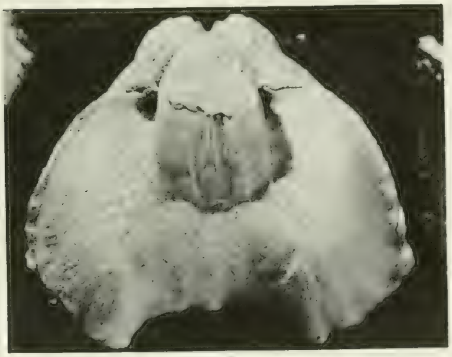
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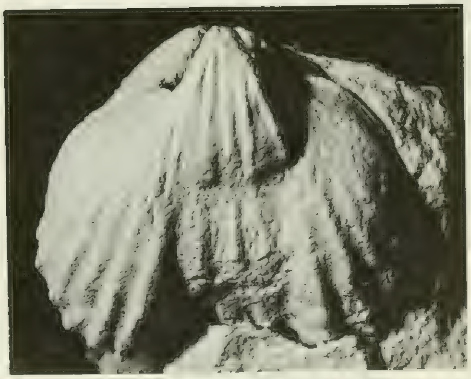
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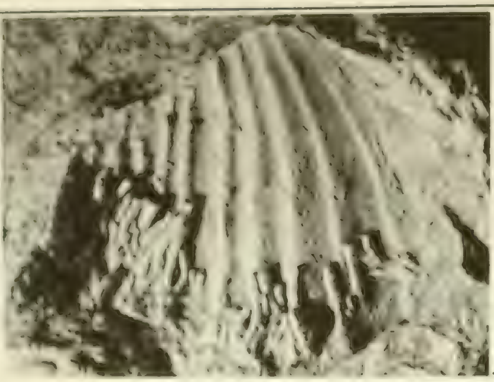
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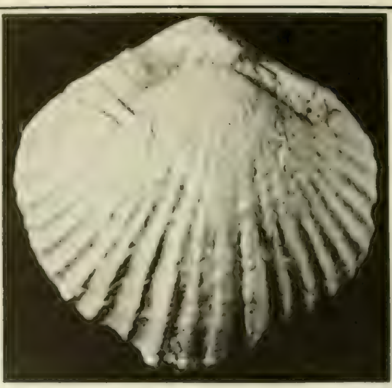
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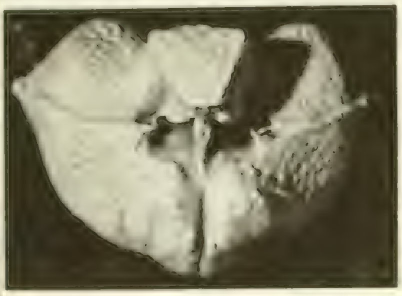
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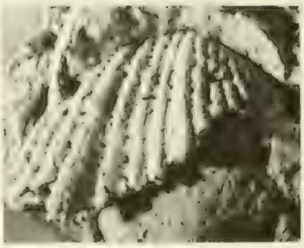
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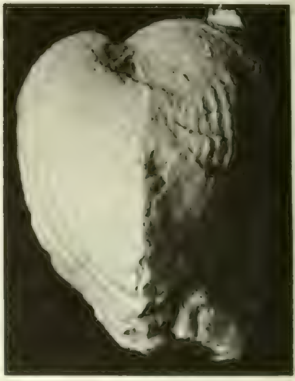
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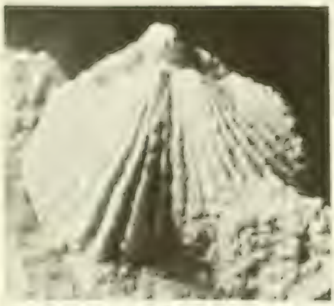
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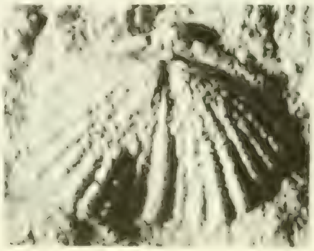
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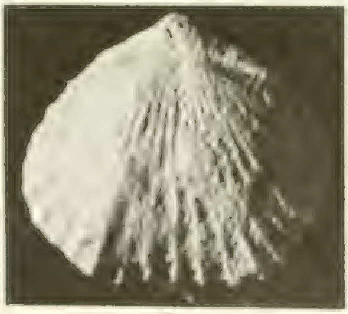
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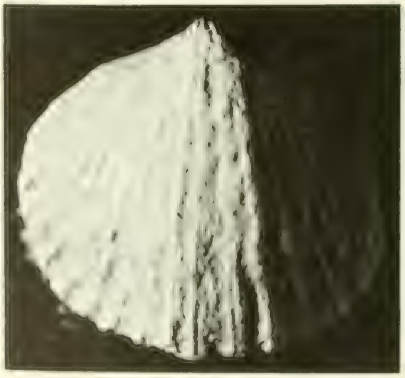
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PLATE 14

Figures 1-5 (×2), Figures 6-9 (×4).

Figs. 1-5. *Orthorhynchula linneyi* (James) .... p. 91

1. YPM 25896, Loc. 203 (A-6308), external mold (natural), concentration of worm tubes along anterior inhalent margins. Image reversed.
2. YPM 25897, Loc. 203 (A-6303), brachial valve up.
3. YPM 25898, Loc. 203 (A-6307), internal mold (natural) pedicle valve up.
4. YPM 25899, Loc. 203 (A-6308), latex impression of external mold showing small worm tubes covering surface of valve; tubes concentrated along each radial interspace.
5. YPM 25900, Loc. 185 (A-6484), pedicle valve left.

Figs. 6-7. *Zygospira modesta* (Hall) .... p. 96

6. YPM 25901, Loc. 110 (A-6425).
7. YPM 25902, Loc. 110 (A-6425).

Figs. 8-9. *Zygospira recurvirostra* (Hall) .... p. 98

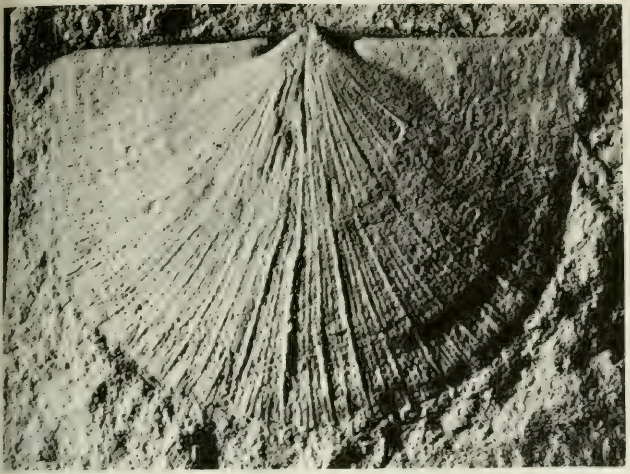
8. YPM 25903, Loc. 141 (A-6448).
9. YPM 25904, Loc. 141 (A-6448).

PLATE 15

All figures are ×2.

Figs. 1-6. *Rafinesquina "alternata"* (Hall) ....p. 87

1. YPM 25905, Loc. 37 (4) (A-6363), pedicle valve internal mold (natural).
2. YPM 25906, Loc. 31 (A-6341), pedicle valve external.
3. YPM 25907, Loc. 31 (A-6341), pedicle valve external.
4. YPM 25908, Loc. 98 (1) (A-6414), pedicle valve internal mold (natural).
5. YPM 25909, Loc. 183 (A-6482), pedicle valve internal mold (natural).
6. YPM 25910, Loc. 49 (A-6376), pedicle valve internal mold (natural).



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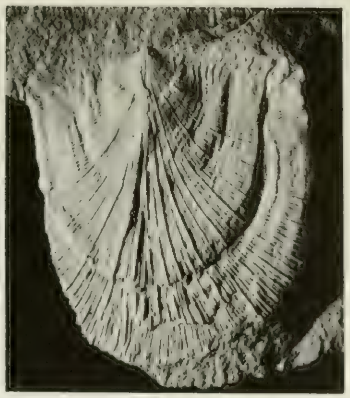

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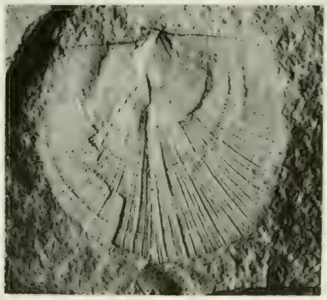

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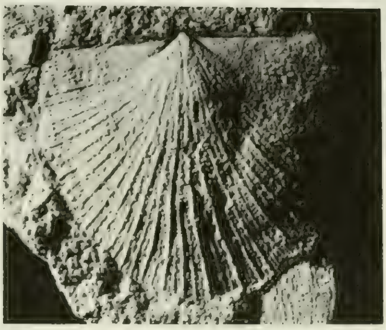

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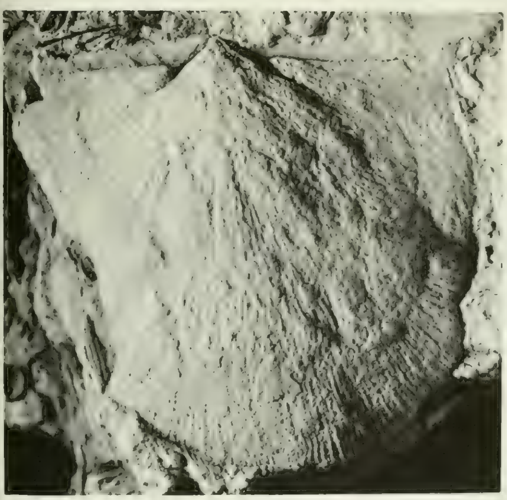

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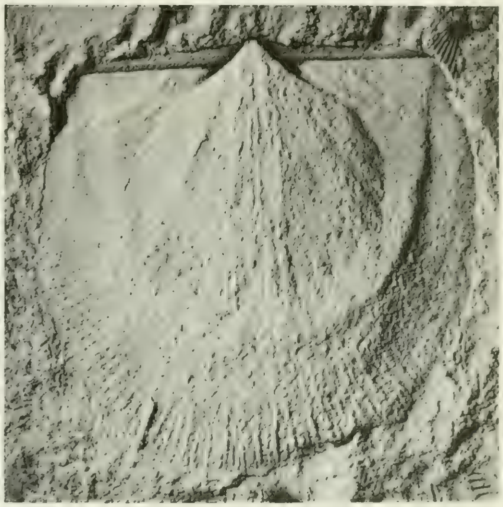

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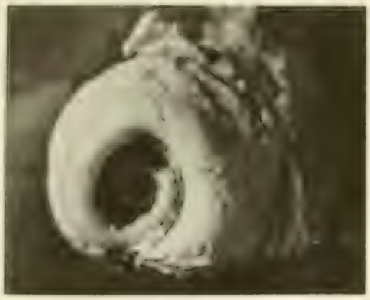
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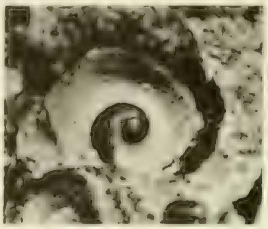
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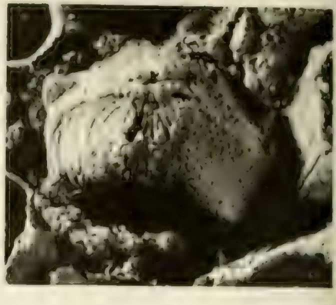
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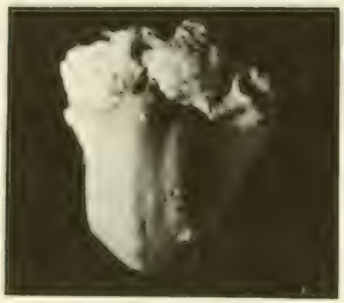
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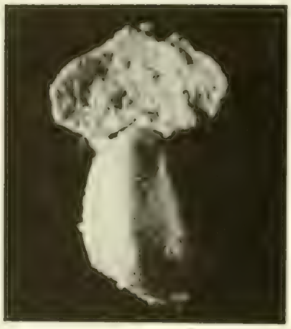
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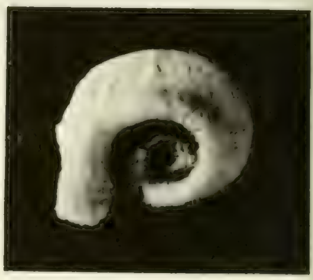
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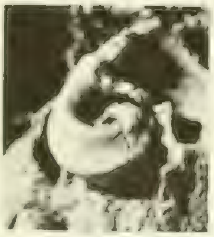
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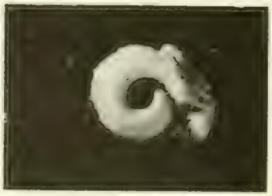
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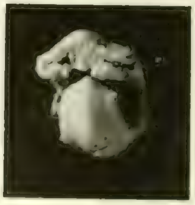
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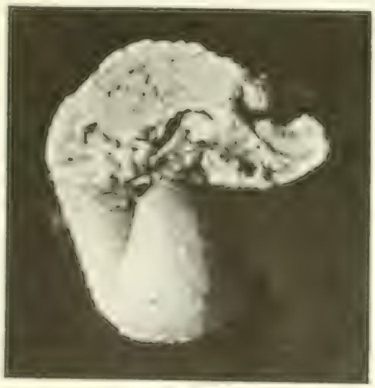
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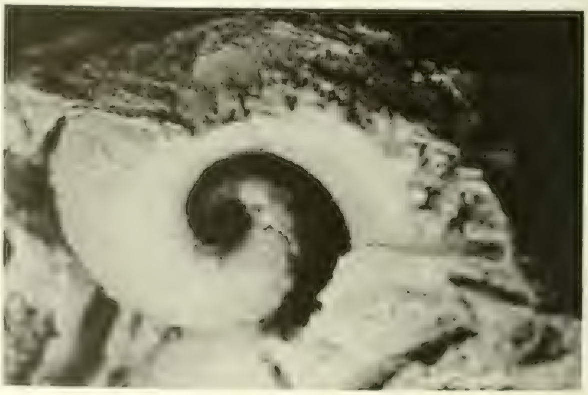
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PLATE 16

All figures are ×4.

Figs. 1-9. *Plectonotus*? sp. . . . . p. 101

1. YPM 25911, Loc. 203 (A-6316).
2. YPM 25912, Loc. 203 (A-6310).
3. YPM 25911, Loc. 203, (A-6316), latex impression of the external mold of fig. 1.
4. YPM 25913, Loc. 148 (A-6454).
5. YPM 25914, Loc. 203 (A-6316).
6. YPM 25915, Loc. 203 (A-6316). Specimen lost.
7. YPM 25916, Loc. 203 (A-6308).
8. YPM 25917, Loc. 203 (A-6316).
9. YPM 25918, Loc. 203 (A-6316).

Figs. 10-11. *Bucania* sp. . . . . p. 102

10. YPM 25919, Loc. 87 (A-6404).
11. YPM 25920, Loc. 87 (A-6404).

PLATE 17

All figures are ×4 except fig. 2 (×2).

Figs. 1-3. *Bucania* sp. . . . . p. 102

1. YPM 25921, Loc. 203 (A-6303).
2. YPM 25922, Loc. 87 (A-6404).
3. YPM 25923, Loc. 87 (A-6404).

Figs. 4. Genus *Seelya* . . . . p. 105

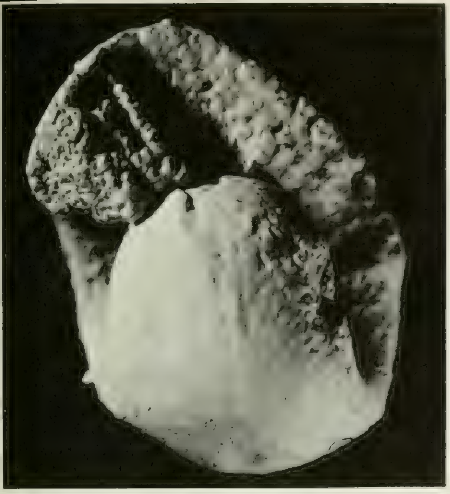
4. YPM 25924, Loc. 167 (A-6467).

Figs. 5. Genus *Cyclonema* . . . . p. 106

5. YPM 25925, Loc. 75 (A-6395).

Figs. 6. Genus *Trochonema* . . . . p. 110

6. YPM 25926, Loc. 101 (4) (A-6417).



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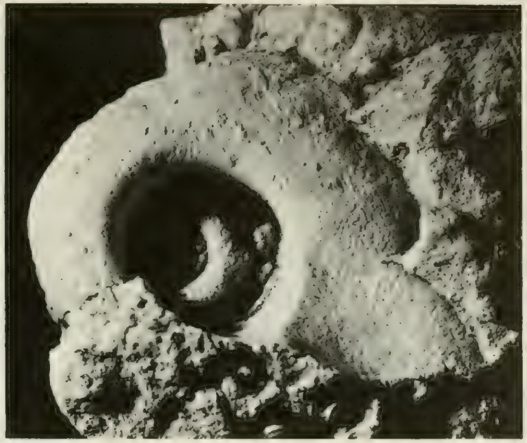

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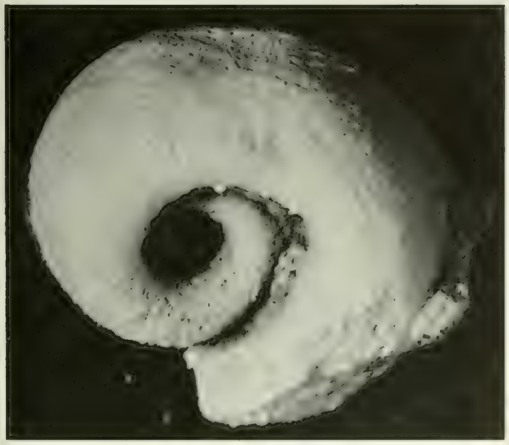

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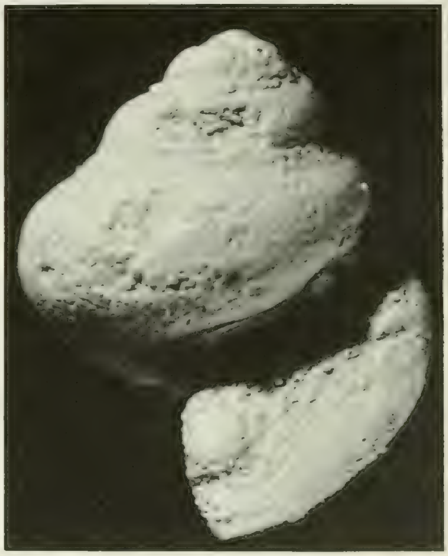

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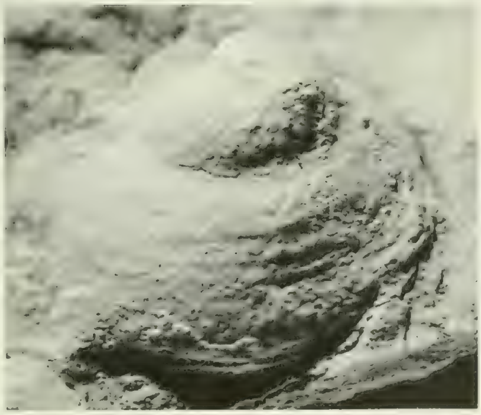

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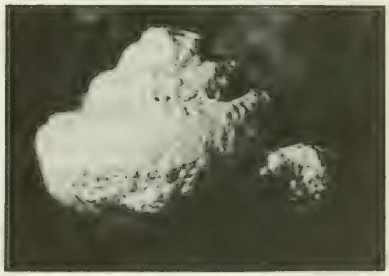

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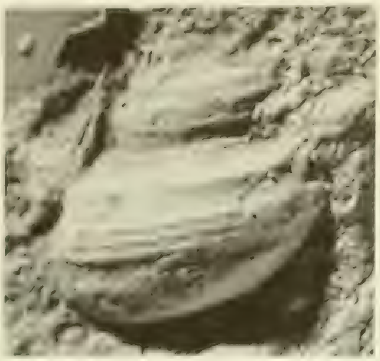

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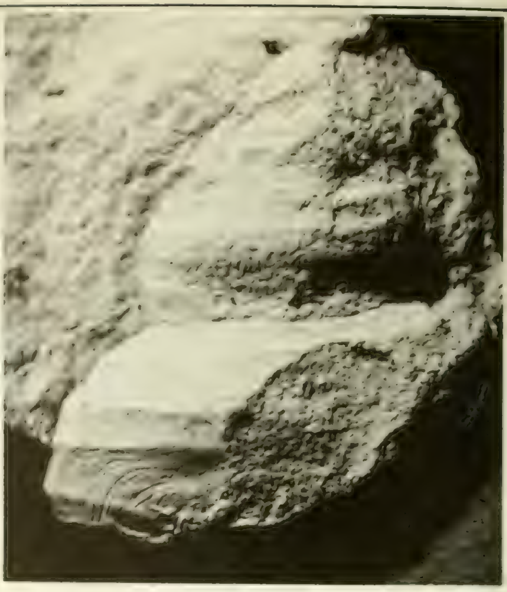

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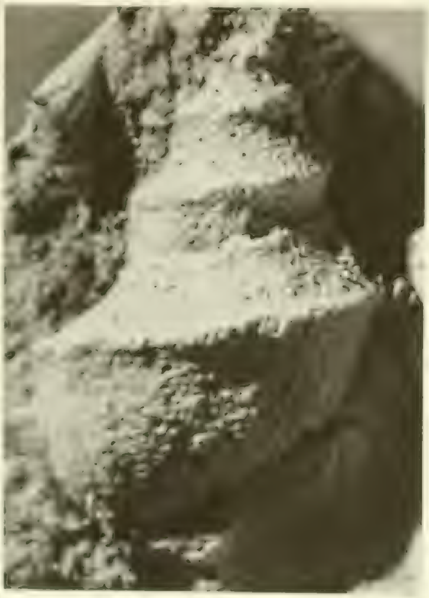

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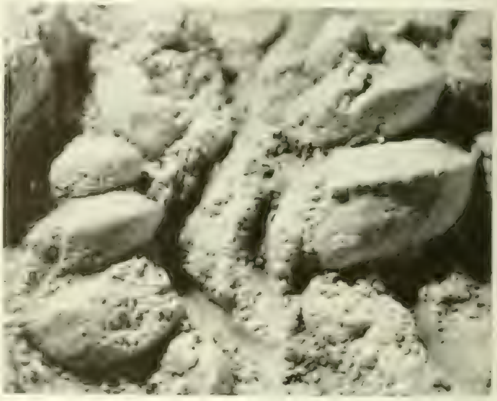

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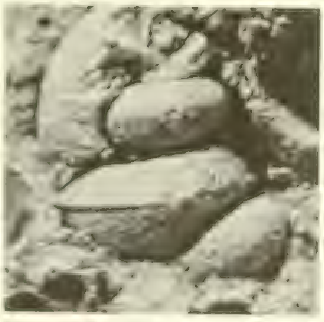

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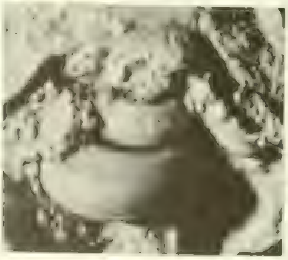

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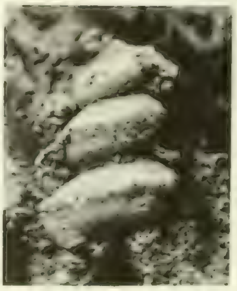

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PLATE 18

All figures are ×4.

Figs. 1-2. *Ruedemannia? lirata* (Ulrich & Scofield) ....p. 104

1. YPM 25927, Loc. 50 (A-6377), latex impression showing pronounced trilineate banding.
2. YPM 25928, Loc. 34-A (A-6345), bilineate banding and fine growth lines well-preserved.

Fig. 3. *Loxoplocus (Lophospira) ventricosta* (Hall) ....p. 108

3. YPM 25929, Loc. 167 (A-6467), latex impression.

Figs. 4-6. *Loxoplocus (Lophospira) abbreviata* (Hall) ....p. 106

4. (right) — YPM 25931, Loc. 179 (A-6478).
5. YPM 25932, Loc. 167 (A-6467).
6. YPM 25933, Loc. 203 (A-6316).

Figs. 4, 7. *Loxoplocus (Lophospira) perangulata* (Hall) ....p. 109

4. (left) — YPM 25930, Loc. 179 (A-6478).
7. YPM 25934, Loc. 179 (A-6478).

PLATE 19

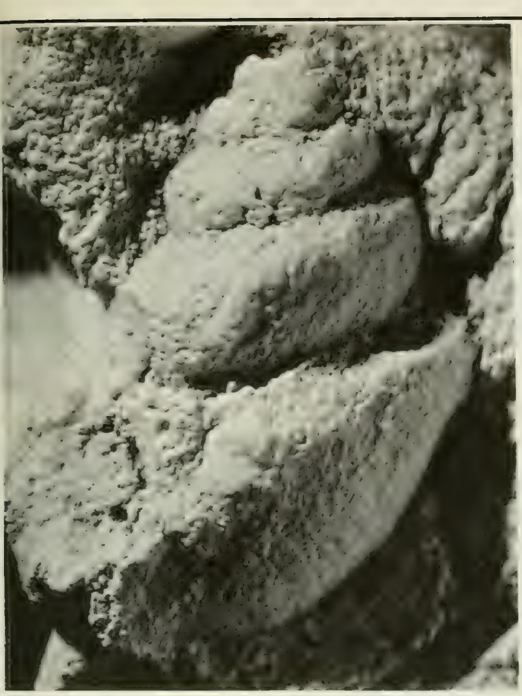
All figures are ×4 except fig. 3 (×2).

Figs. 1-2. Genus *Sinuopea?* .... p. 110

1. YPM 25935, Loc. 167 (A-6467).
2. YPM 25936, Loc. 167 (A-6467), latex impression.

Figs. 3-4. Genus *Murchisonia?* .... p. 111

3. YPM 25937, Loc. 133 (A-6441).
4. YPM 25938, Loc. 133 (A-6441).



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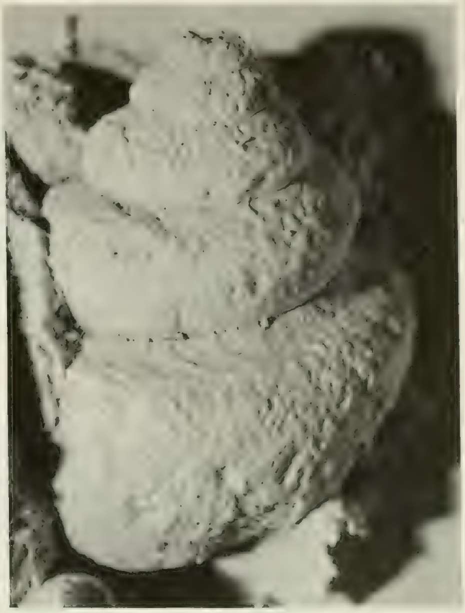

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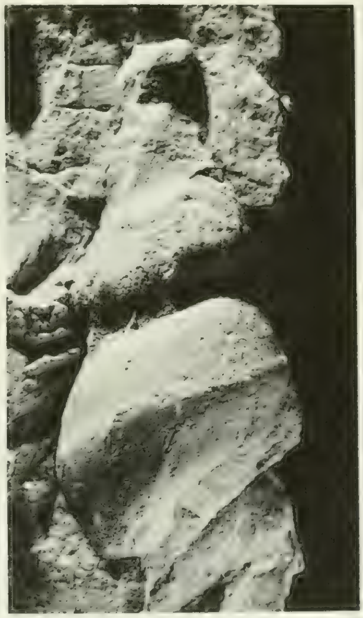

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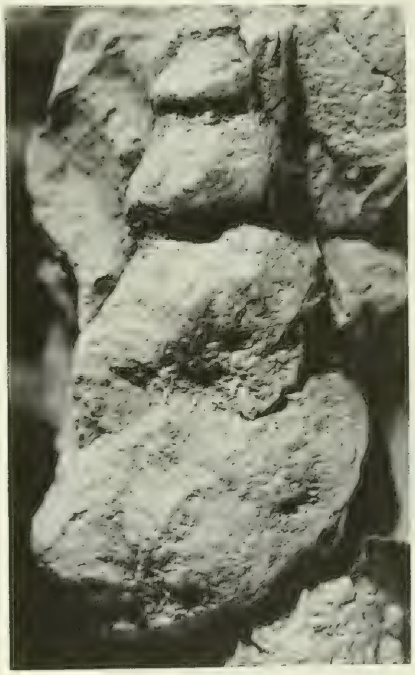

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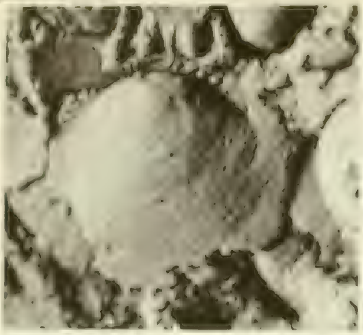

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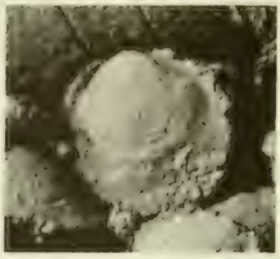

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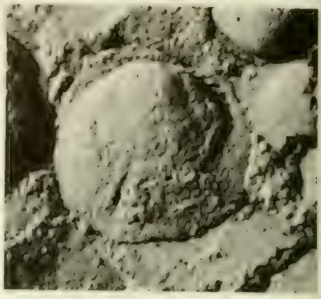

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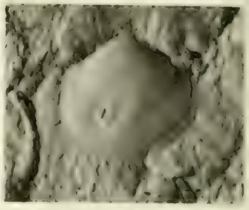

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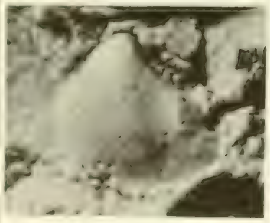

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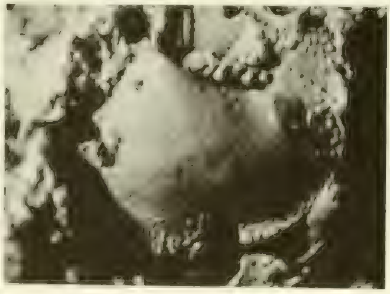

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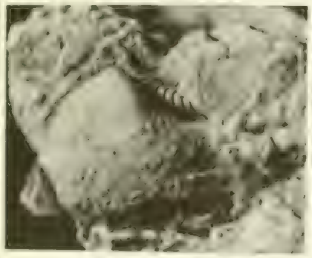

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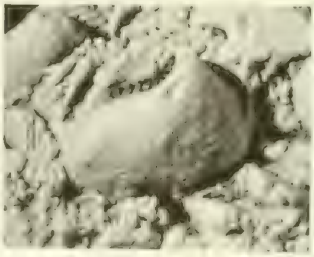

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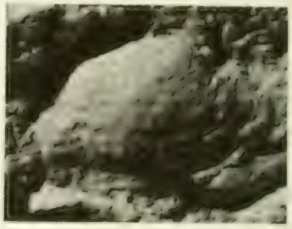

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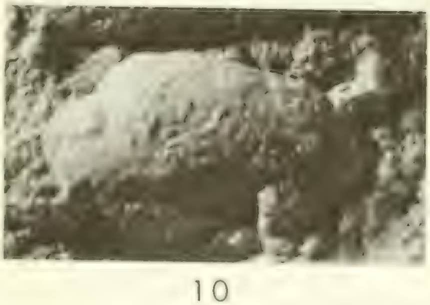

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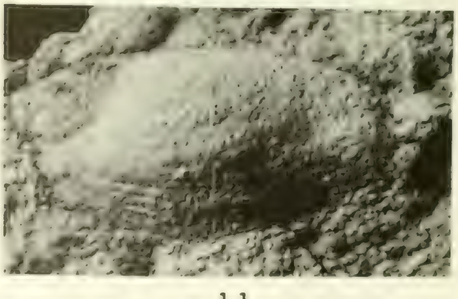

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PLATE 20

All figures are ×4.

Figs. 1-3. *Ctenodonta*? *pulchella* (Hall) ....p. 112
  1. YPM 25939, Loc. 37 (A-6359).
  2. YPM 25940, Loc. 37 (A-6359).
  3. YPM 25941, Loc. 37 (A-6359).

Fig. 4. Probable *Ctenodonta*? *pulchella* (Hall) ....p. 112
  4. YPM 25942, Loc. 34 (A) (A-6345).

Figs. 5-8. *Praenucula levata* (Hall) ....p. 114
  5. YPM 25943, Loc. 37 (A-6359).
  6. YPM 25944, Loc. 97 (11) (A-6413).
  7. YPM 25945, Loc. 77-A (A-6397).
  8. YPM 25946, Loc. 37 (A-6359).

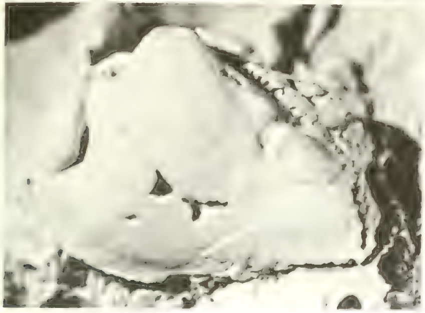
Figs. 9-11. Probable Genus *Palaeoneilo* ....p. 114
  9. YPM 25947, Loc. 135 (A-6443).
  10. YPM 25948, Loc. 135 (A-6443).
  11. YPM 25949, Loc. 148 (A-6454).

PLATE 21

All figures are ×4.

Figs. 1-7. *Tancrediopsis cuneata* (Hall) ....p. 113

1. YPM 25950, Loc. 203 (A-6316).
2. YPM 25951, Loc. 203 (A-6317).
3. YPM 25952, Loc. 203 (A-6316).
4. YPM 25953, Loc. 84 (A-6402).
5. YPM 25954, Loc. 75 (A-6395).
6. YPM 25955, Loc. 82 (A-6400).
7. YPM 25956, Loc. 82 (A-6400).



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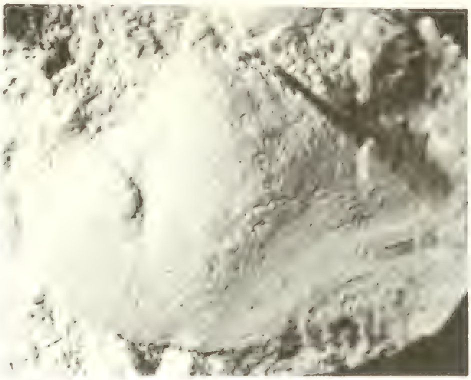

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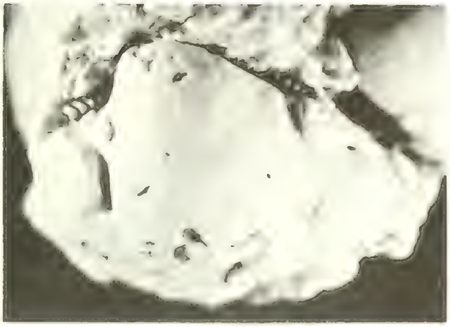

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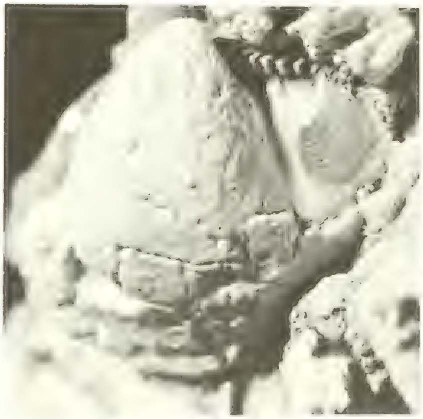

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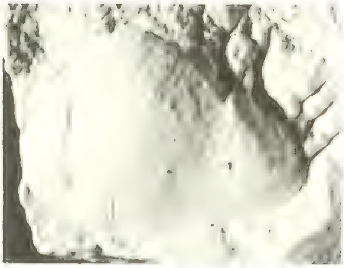

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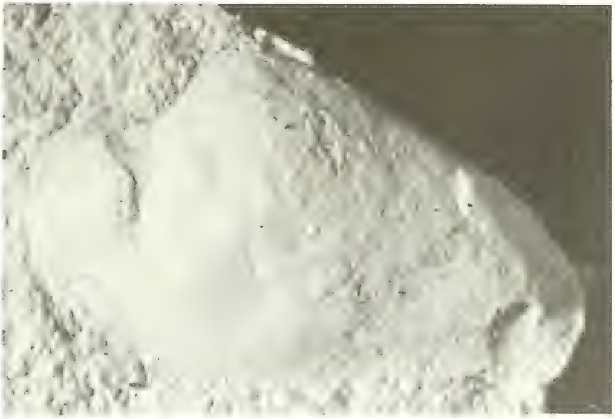

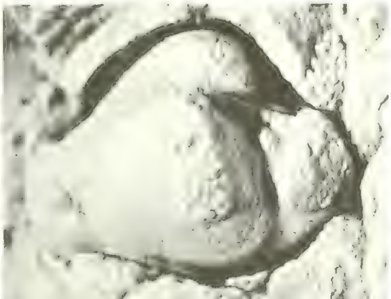

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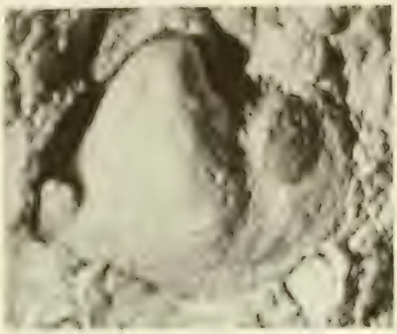

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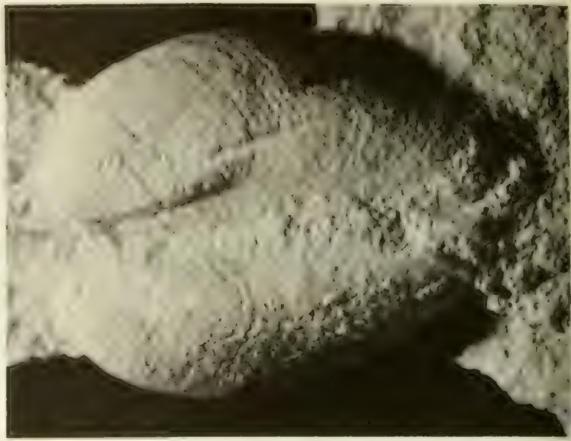

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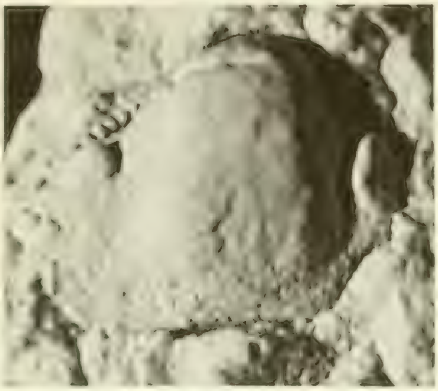

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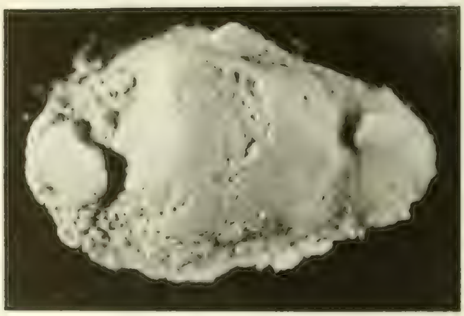

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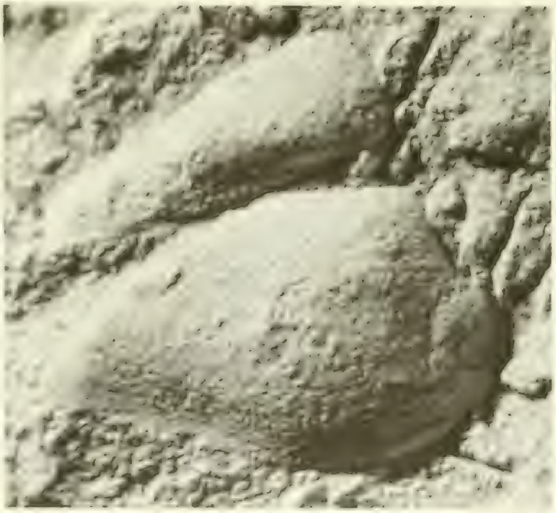

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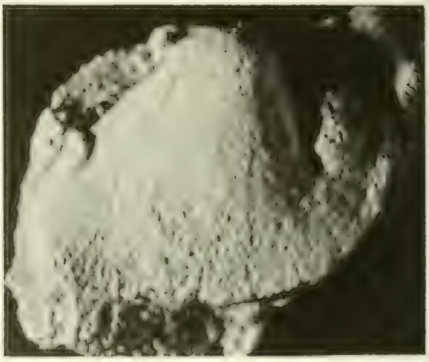

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PLATE 22

All figures are ×4.

Figs. 1-6. *Tancrediopsis cuneata* (Hall) ....p. 113

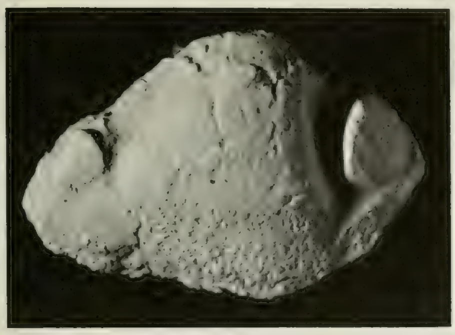
1. YPM 25957, Loc. 203 (A-6309).
2. YPM 25958, Loc. 188 (A-6486).
3. YPM 25959, Loc. 203 (A-6308).
4. YPM 25960, Loc. 203 (A-6304).
5. YPM 25961, Loc. 201 (A-6497).
6. YPM 25962, Loc. 193 (A-6490).

PLATE 23

All figures are ×4.

Figs. 1-5. *Tancrediopsis cuneata* (Hall) ....p. 113

1. YPM 25963, Loc. 203 (A-6313).
2. YPM 25964, Loc. 200 (A-6496).
3. (right) — YPM 25966, Loc. 203 (A-6316).
   (left) — YPM 25965, Loc. 203 (A-6316).
4. YPM 25967, Loc. 203 (A-6316).
5. YPM 25968, Loc. 203 (A-6316).



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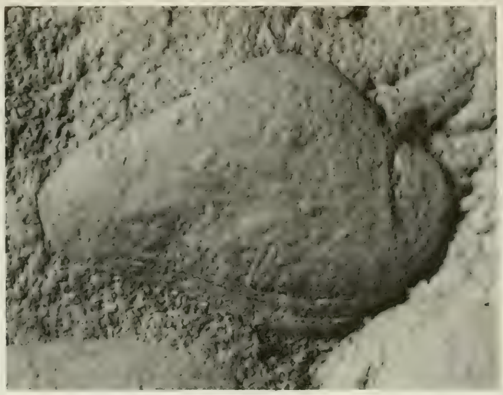

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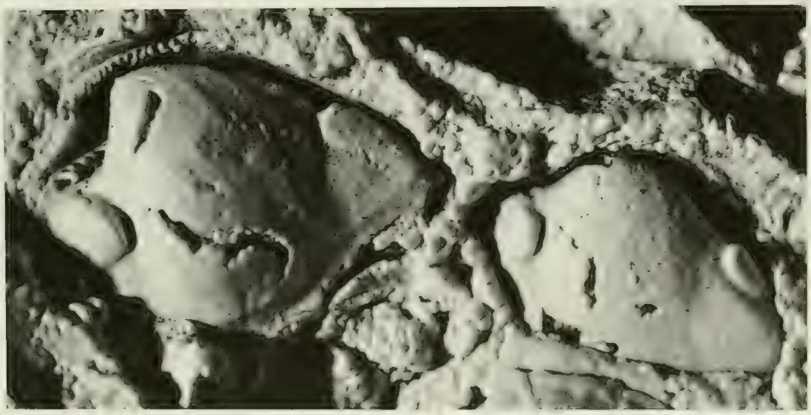

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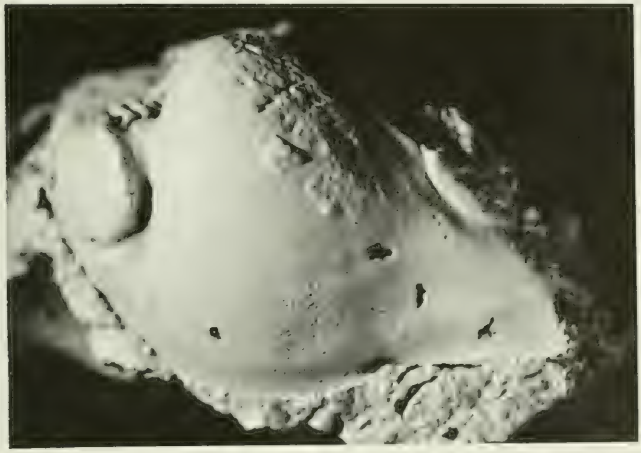

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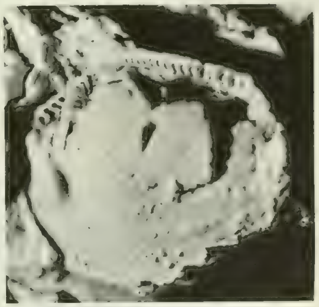

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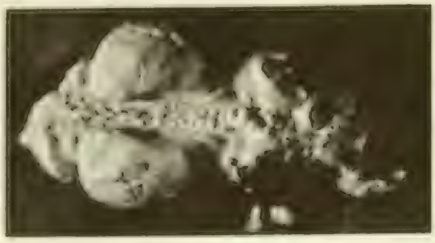

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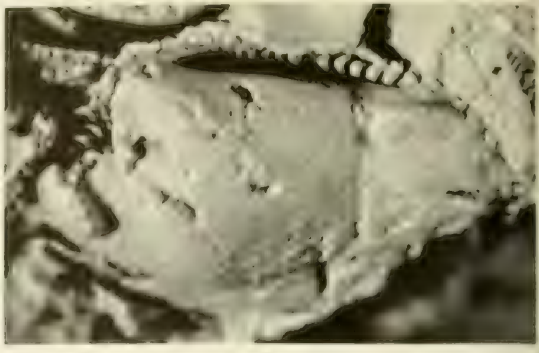

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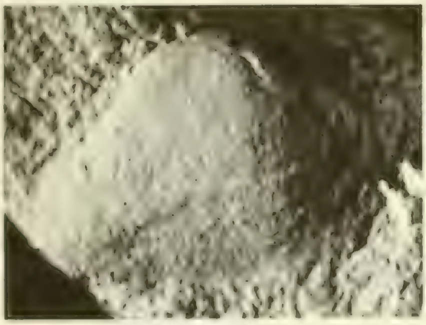

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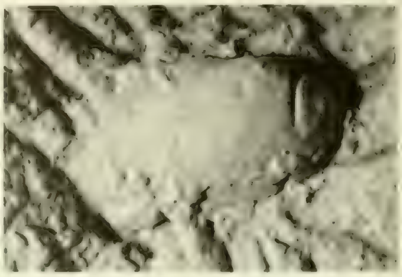

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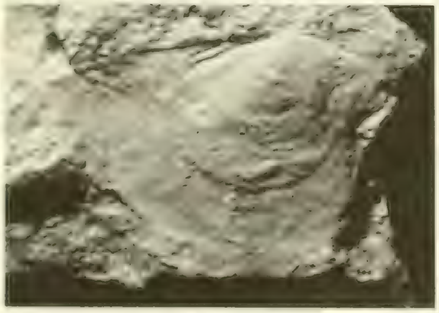

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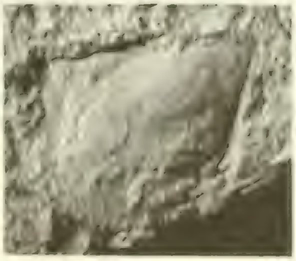

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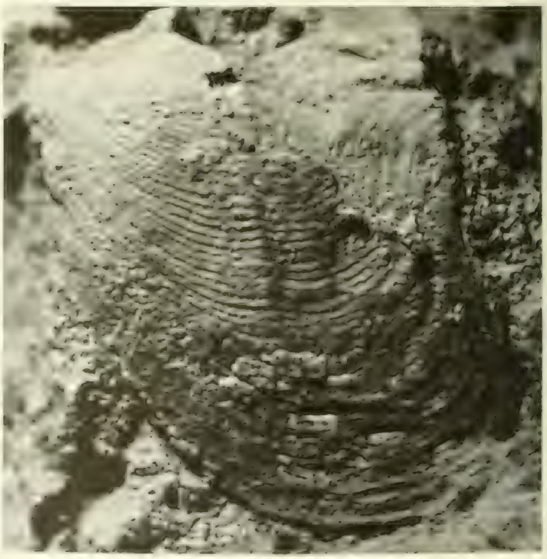

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PLATE 24

All figures are ×4 except figs. 5, 6 (×2).

Figs. 1-3. *Tancrediopsis cuneata* (Hall) ....p. 113

1. YPM 25969, Loc. 97 (4) (A-6413).
2. YPM 25970, Loc. 84 (A-6402).
3. YPM 25971, Loc. 75 (A-6395).

Fig. 4. Genus *Nuculites* ....p. 117

4. YPM 25972, Loc. 34-A (A-6345).

Figs. 5-7. *Pterinea* (*Caritodens*) *demissa* (Conrad) ....p. 124

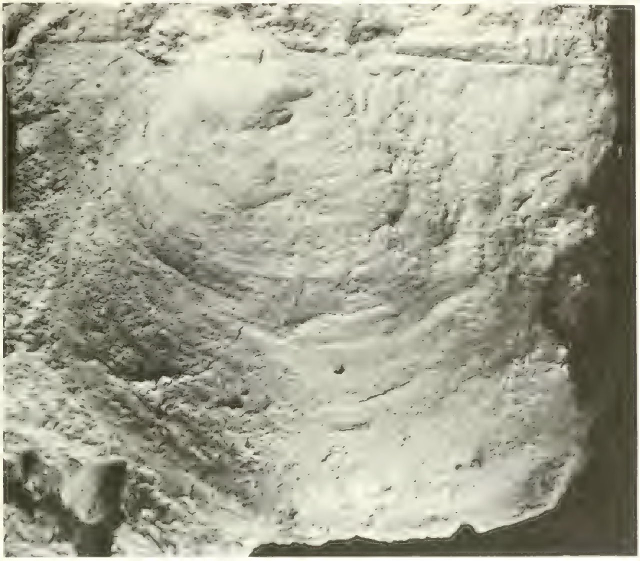
5. YPM 25973, Loc. 152 (A-6548), internal mold (natural) of right valve showing pronounced posterior lateral socket.
6. YPM 25974, Loc. 152 (A-6548), internal mold (natural) of right valve showing partial impression of large posterior adductor.
7. YPM 25975, Loc. 203 (A-6303), showing obliquely prosoclinal shape characteristic of smaller species.

PLATE 25

All figures are ×2 except fig. 3 (×4).

Figs. 1-5. *Pterinea* (*Caritodens*) *demissa* (Conrad) ....p. 124

1. YPM 25976, Loc. 203 (A-6303), showing obtuse, rounded shape characteristic of larger specimens.
2. YPM 25977, Loc. 149 (A-6455).
3. YPM 25976, similar to fig. 1 only higher magnification showing the duplivincular ligament.
4. YPM 25978, Loc. 150 (A-6456).
5. YPM 25979, Loc. 203 (A-6303), internal mold (natural) of left valve showing impression of posterior lateral tooth or jugum.



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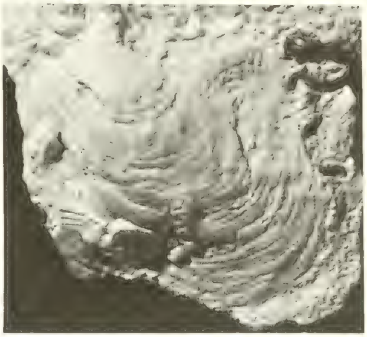

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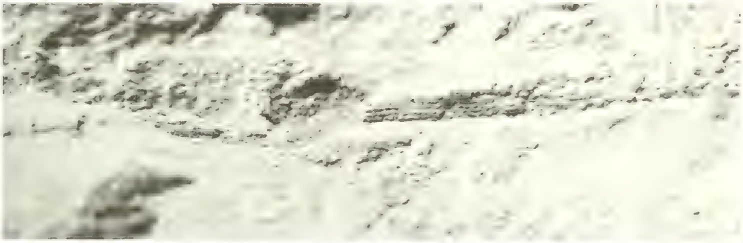

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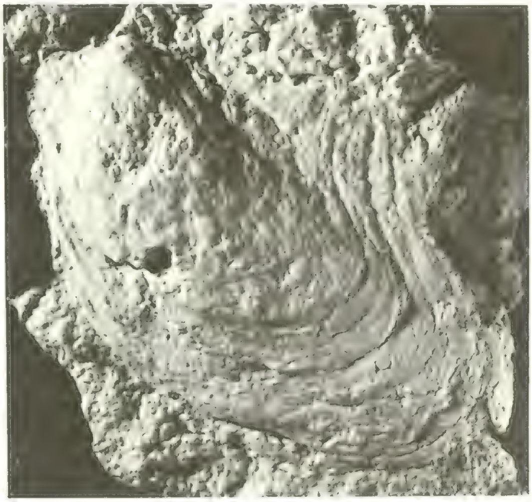

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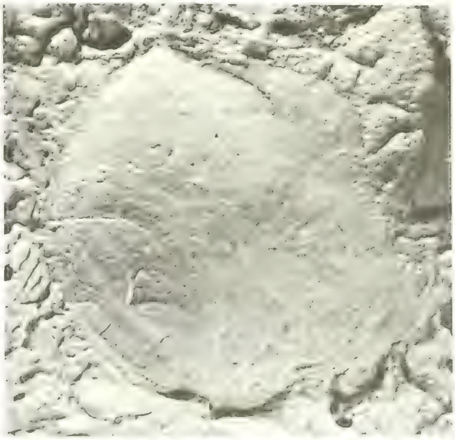

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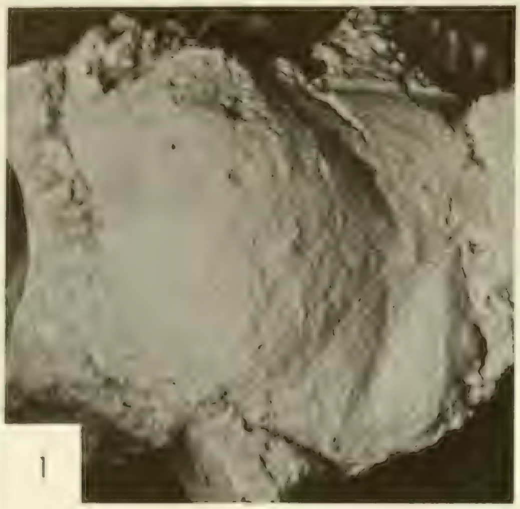
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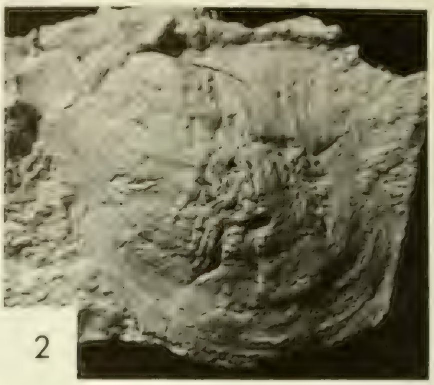
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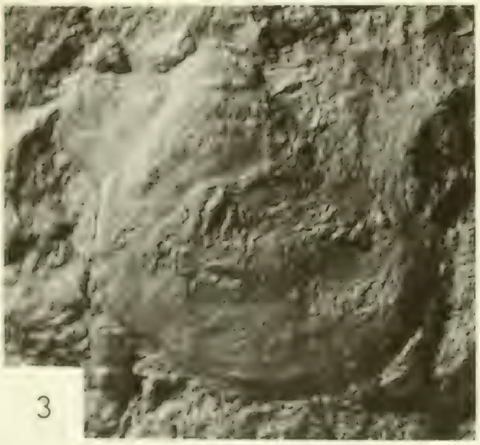
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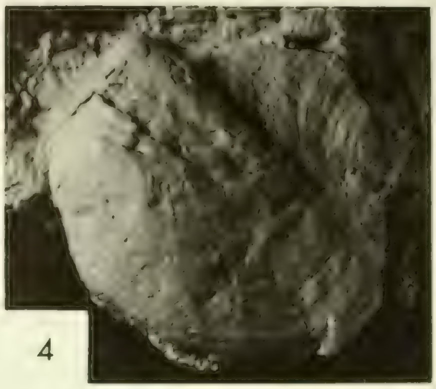
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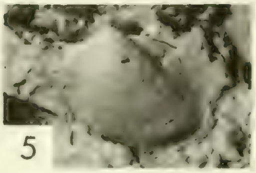
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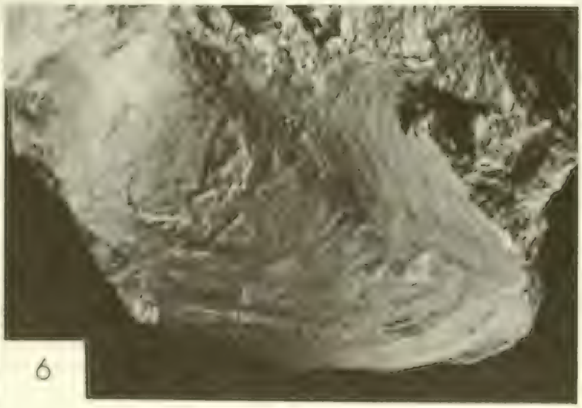
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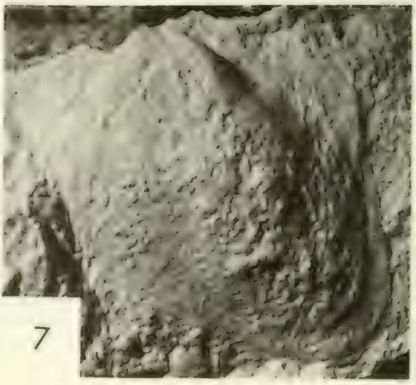
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PLATE 26

All figures are ×2.

Figs. 1-6. *Pterinea* (*Caritodens*) *demissa* (Conrad) .... p. 124
    1. YPM 25980, Loc. 185 (A-6484).
    2. YPM 25981, Loc. 203 (A-6309).
    3. YPM 25982, Loc. 203 (A-6304).
    4. YPM 25983, Loc. 147 (A-6453).
    5. YPM 25984, Loc. 186 (A-6323).
    6. YPM 25985, Loc. 203 (A-6306).
Fig. 7. Probable *Pterinea* (*Caritodens*) *demissa* (Conrad) .... p. 124
    7. YPM 25986, Loc. 181 (A-6480).

PLATE 27

All figures are ×2.

Fig. 1. *Pterinea (Caritodens) demissa* (Conrad) .... p. 124

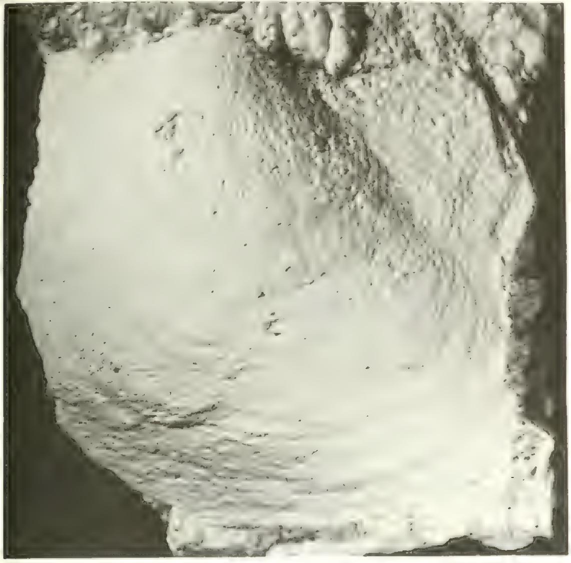
1. YPM 25987, Loc. 170 (A-6470).

Fig. 2. Probable *Pterinea* sp. .... p. 124

2. YPM 25988, Loc. 178 (A-6477).

Figs. 3-6. *Ischyrodonta truncata* Ulrich .... p. 130

3. YPM 25989, Loc. 192 (A-6489).
4. YPM 25990, Loc. 203 (A-6306).
5. YPM 25991, Loc. 203 (A-6311).
6. YPM 25992, Loc. 203 (A-6302), internal mold (natural) showing impression of small, rounded pedal retractors.



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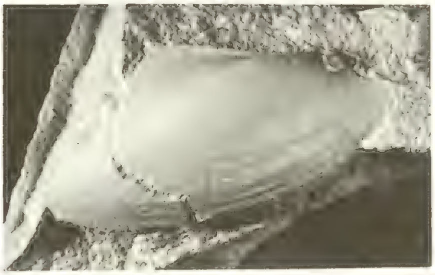

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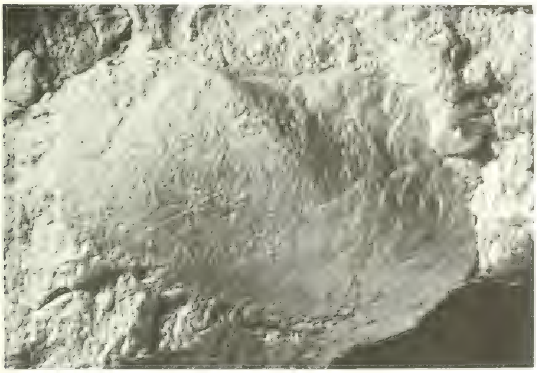

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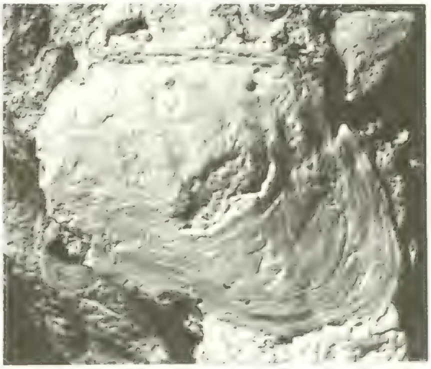

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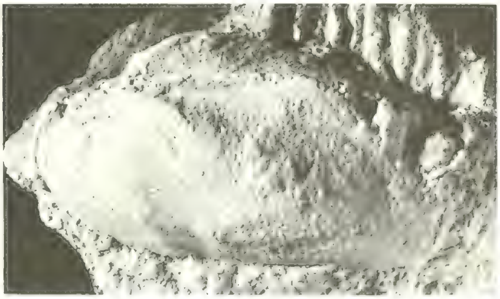

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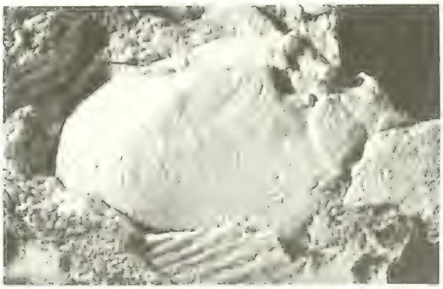

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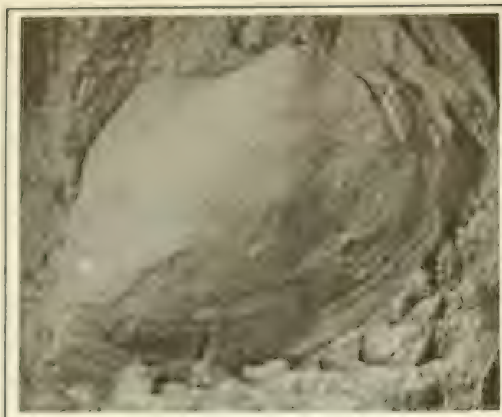

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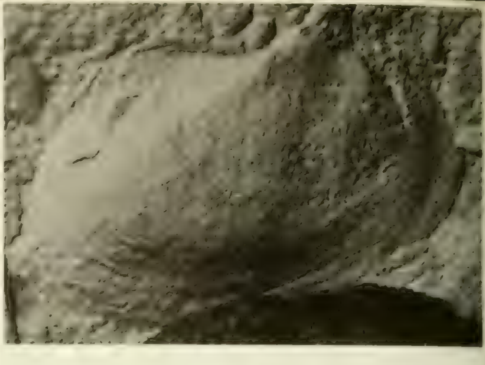

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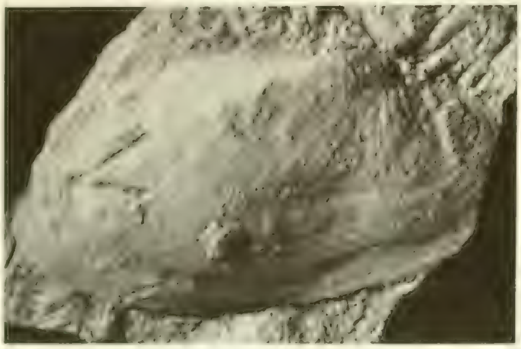

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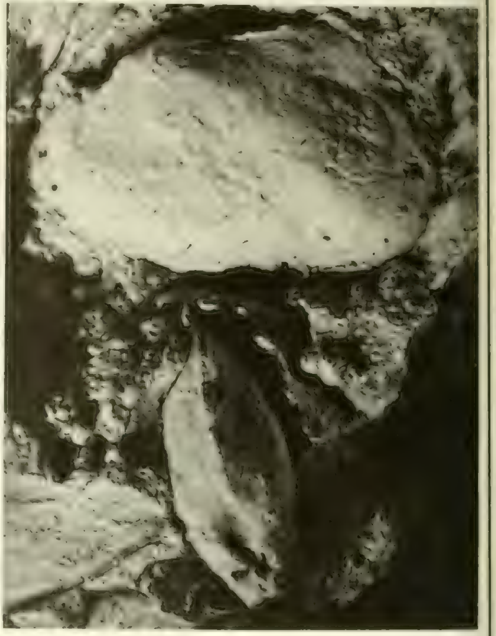

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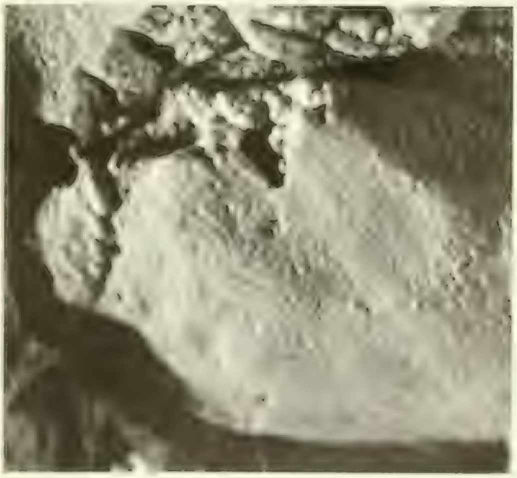

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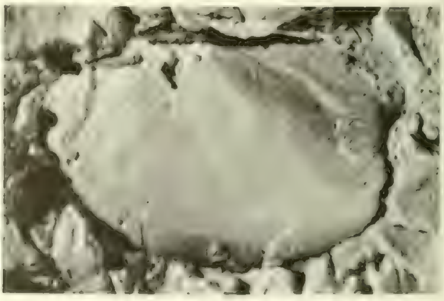

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PLATE 28

All figures are ×2 except fig. 5 (×4).

Figs. 1-6. *Ischyrodonta truncata* Ulrich ....p. 130

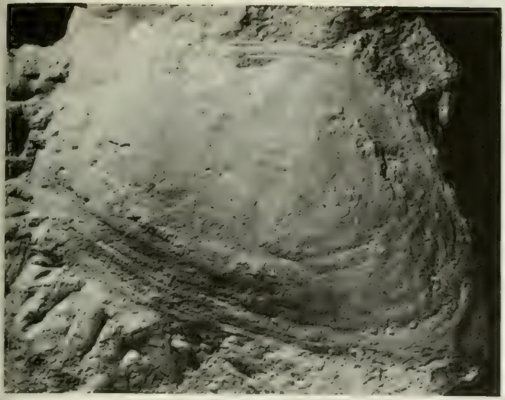
1. YPM 25993, Loc. 98 (A-6414).
2. YPM 25994, Loc. 200 (A-6496).
3. YPM 25995, Loc. 203 (A-6307), showing impression of possible worm tubes at the inhalent opening.
4. (top) — YPM 25996, Loc. 203 (A-6309).
   (bottom) — YPM 25997, Loc. 203 (A-6309).
5. YPM 25998, Loc. 87 (A-6404), internal mold (natural) of left valve showing impression of cardinal dentition.
6. YPM 25998 — Similar to fig. 5, except lower magnification.

PLATE 29

All figures are ×2.

Figs. 1-6. *Ischyrodonta truncata* Ulrich ....p. 130

1. YPM 25999, Loc. 152 (A-6458).
2. YPM 26000, Loc. 38 (A-6364).
3. YPM 26001, Loc. 182 (A-6481), latex impression showing possible worm tubes at the inhalent opening.
4. YPM 26002, Loc. 203 (A-6309).
5. YPM 26003, Loc. 99 (A-6415).
6. YPM 26004, Loc. 203 (A-6310).



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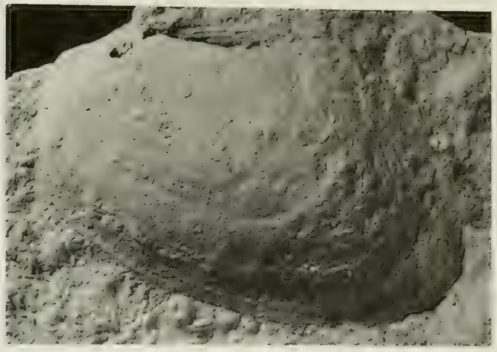

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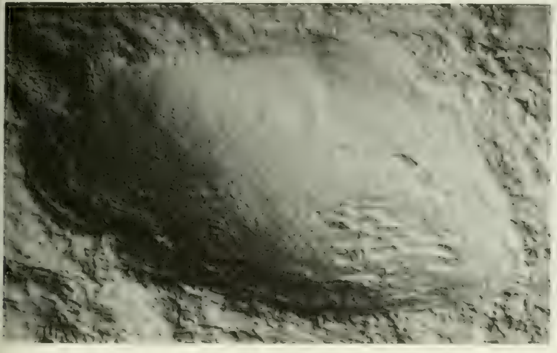

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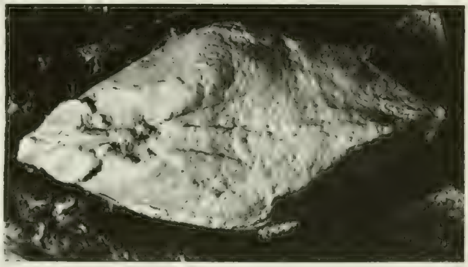

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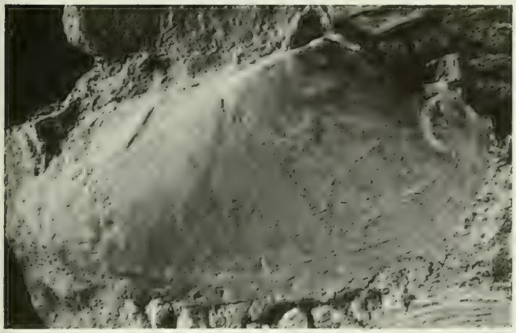

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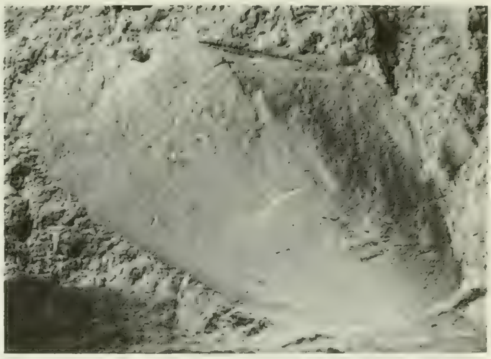

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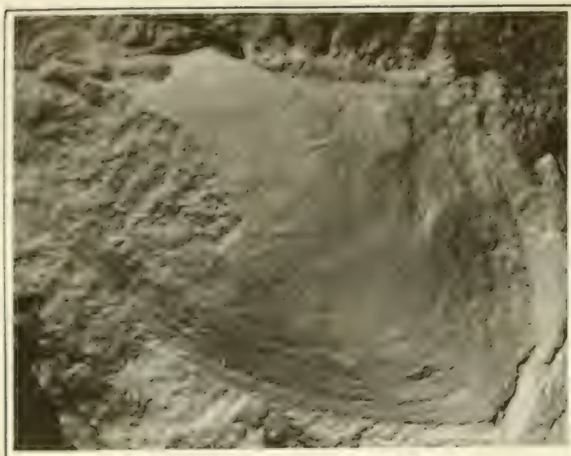

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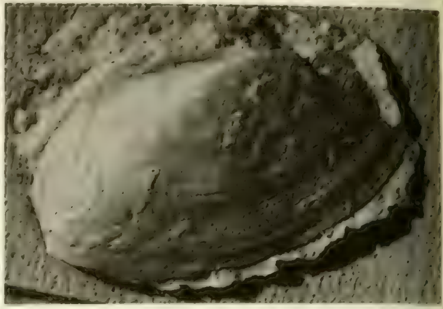

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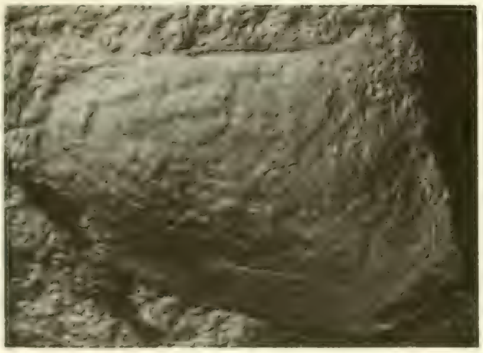

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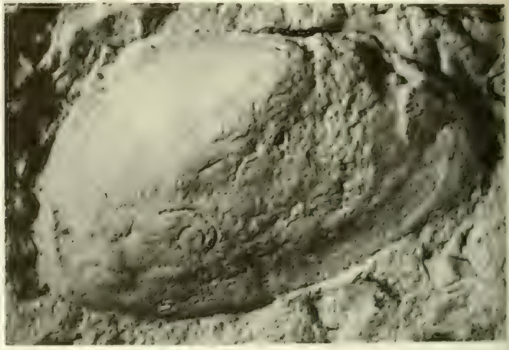

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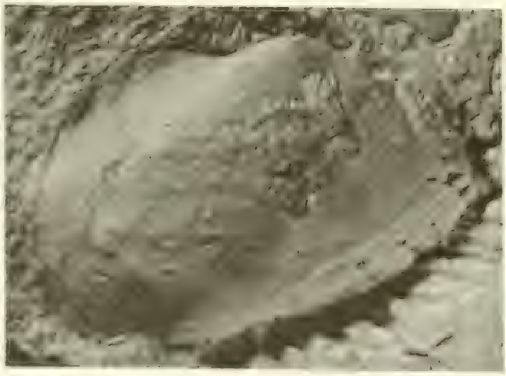

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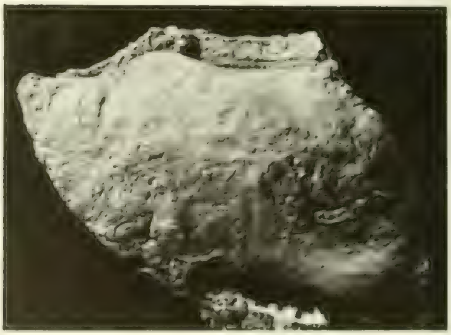

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PLATE 30

All figures are ×2.

Figs. 1-6. *Ischyrodonta truncata* Ulrich .... p. 130

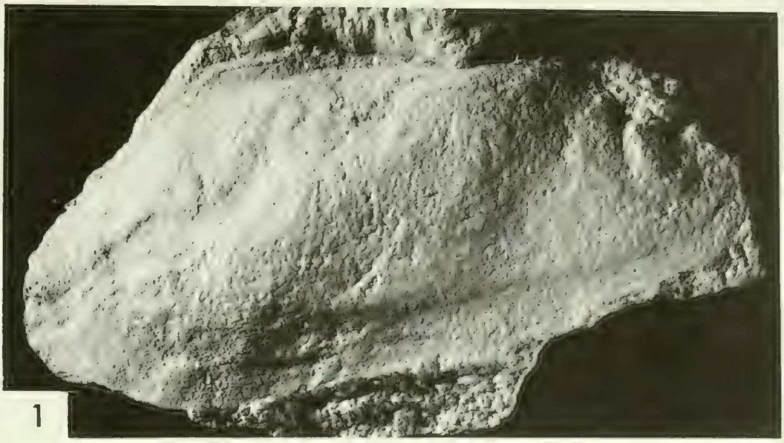
1. YPM 26005, Loc. 152 (A-6458).
2. YPM 26006, Loc. 140 (A-6447), latex impression.
3. YPM 26007, Loc. 203 (A-6308).
4. YPM 26008, Loc. 203 (A-6309).
5. YPM 26009, Loc. 98 (A-6414).
6. YPM 26010, Loc. 203 (A-6303), showing amphidetic, duplivincular ligament.

PLATE 31

All figures are ×2 except fig. 3 (×1.5).

Figs. 1-3. *Modiolopsis modiolaris* (Conrad) ....p. 127

1. YPM 26011, Loc. 203 (A-6303), showing impression of an irregular "U"-shaped tube at the approximate position of the inhalent current.
2. YPM 26012, Loc. 203 (A-6303).
3. YPM 26013, Loc. 203 (A-6307).



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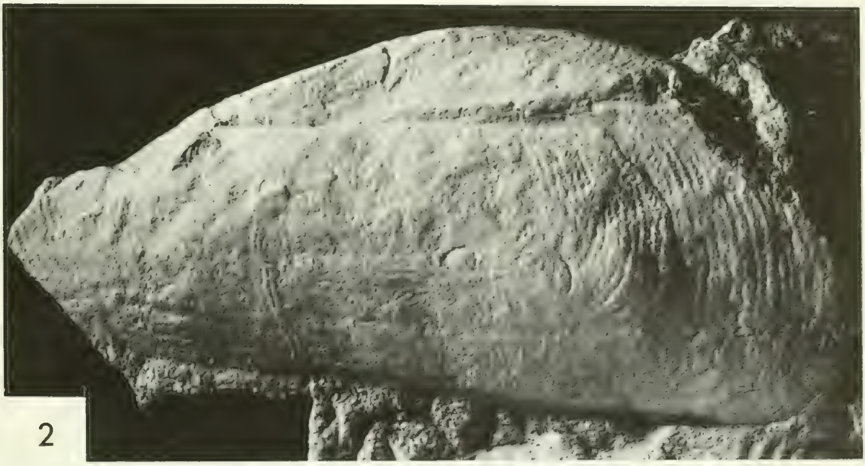

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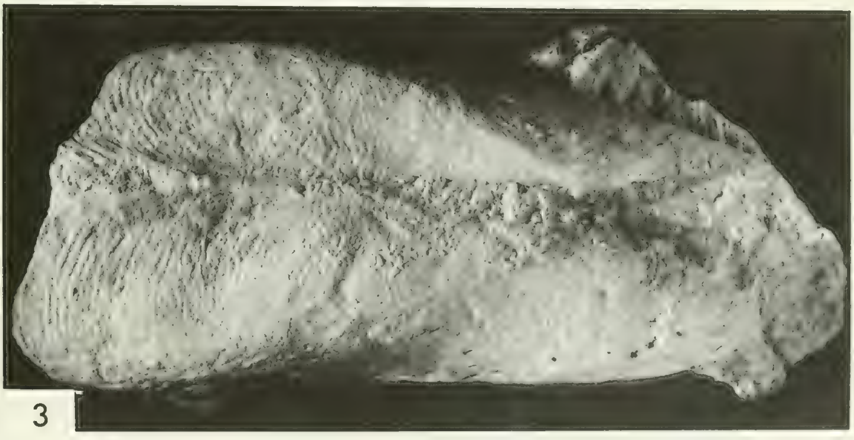

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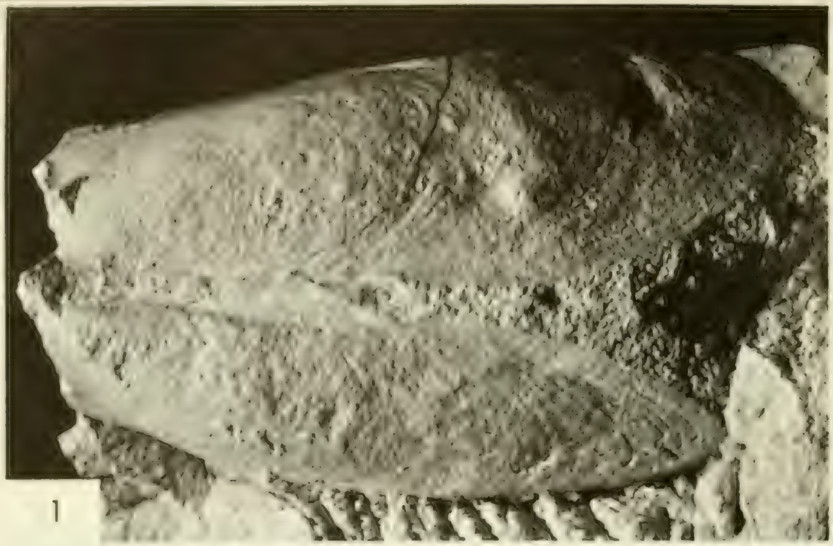

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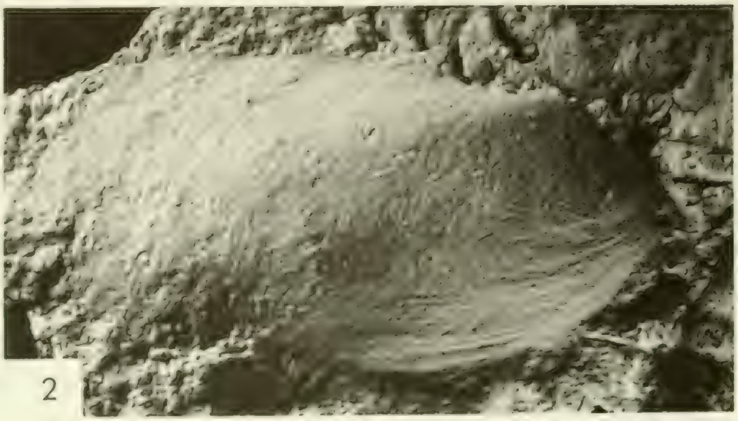

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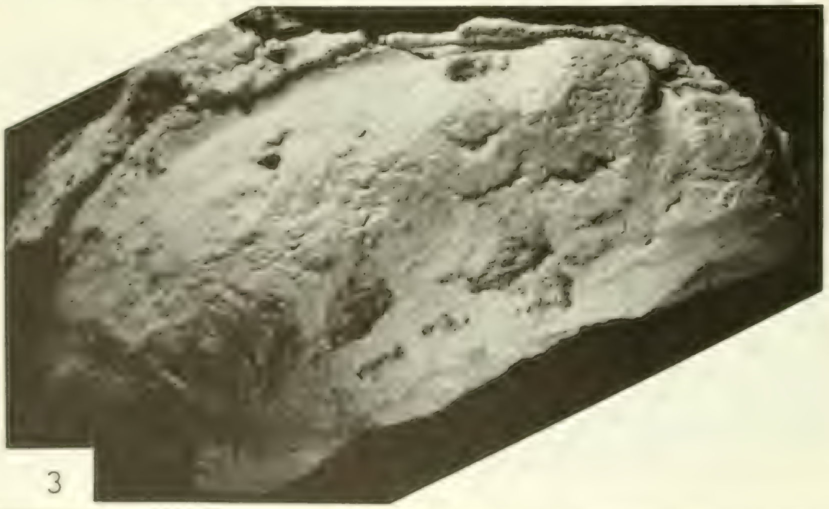

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PLATE 32

All figures are ×2.

Figs. 1, 3. *Modiolopsis modiolaris* (Conrad) .... p. 127

1. YPM 26014, Loc. 63 (B) (A-6383).
3. YPM 26016, Loc. 203 (A-6305), internal mold (natural) showing impression of elongate, broad opisthodetic ligament.

Fig. 2. Probable *Modiolopsis modiolaris* (Conrad) .... p. 127

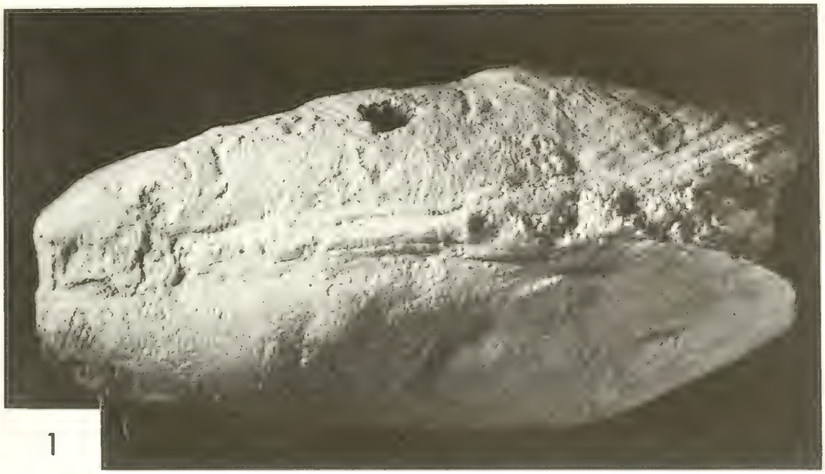
2. YPM 26015, Loc. 52 (A-6380), possibly another species (cf. *M. sinuata*).

PLATE 33

All figures are ×2 except fig. 2 (×1.5).

Figs. 1-3. *Modiolopsis modiolaris* (Conrad) ....p. 127

1. YPM 26017, Loc. 203 (A-6303).
2. YPM 26018, Loc. 171 (A-6471).
3. YPM 26019, Loc. 203 (A-6303).



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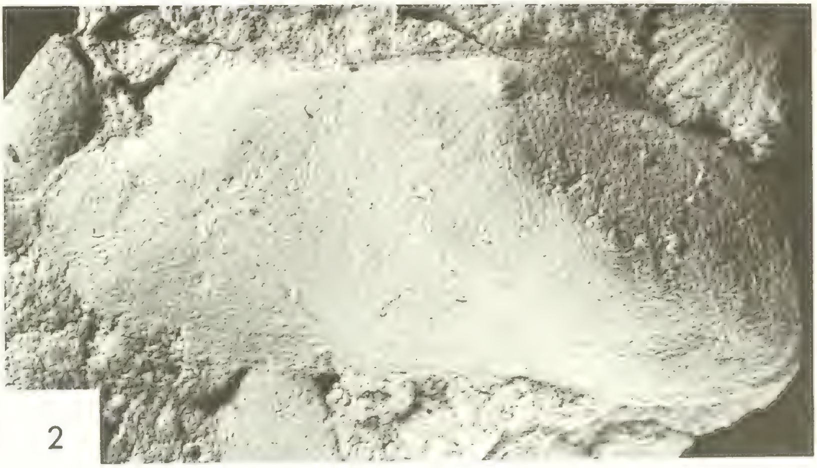

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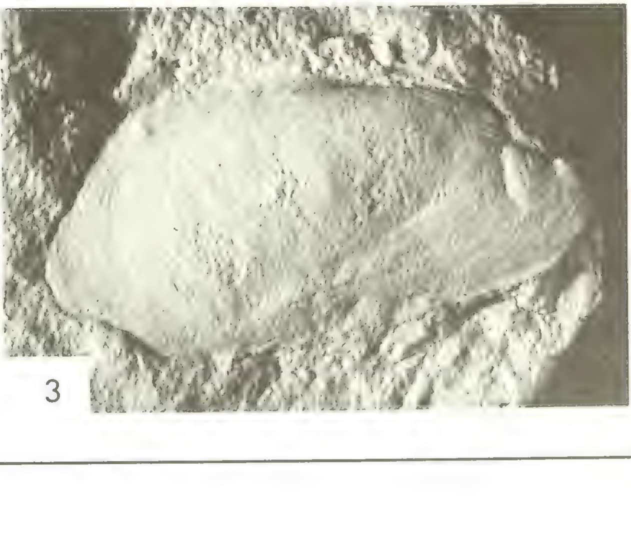

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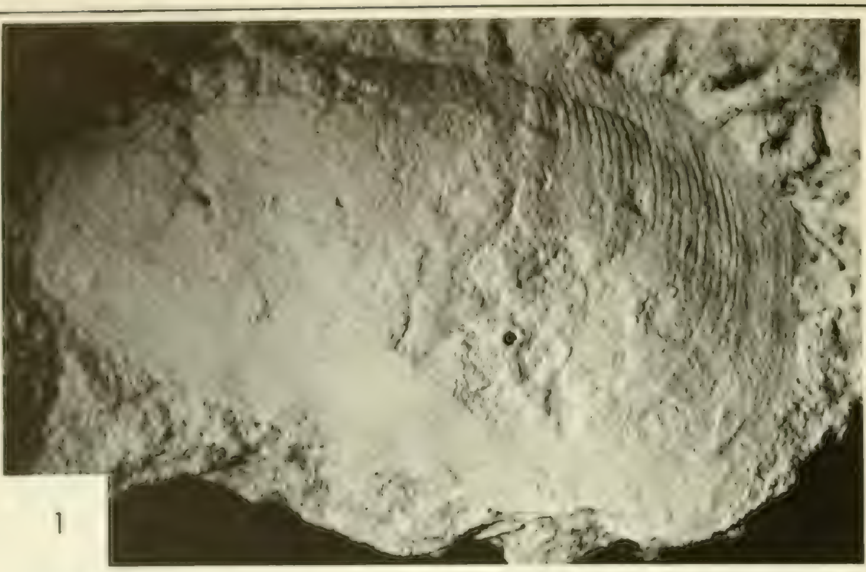

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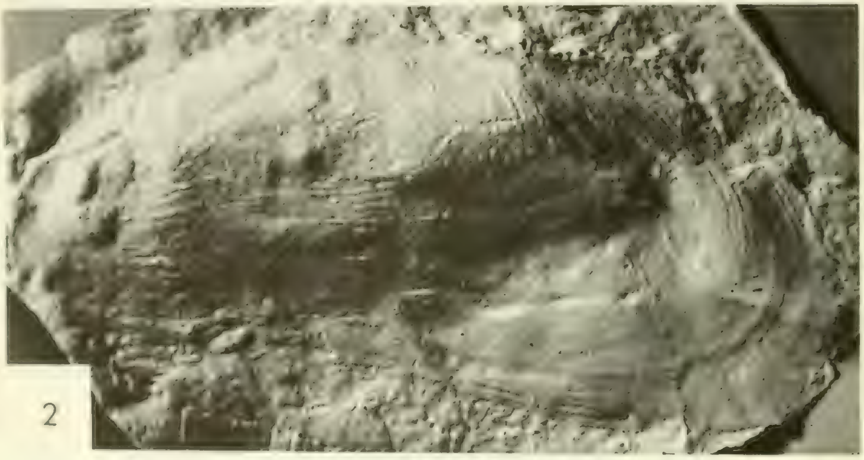

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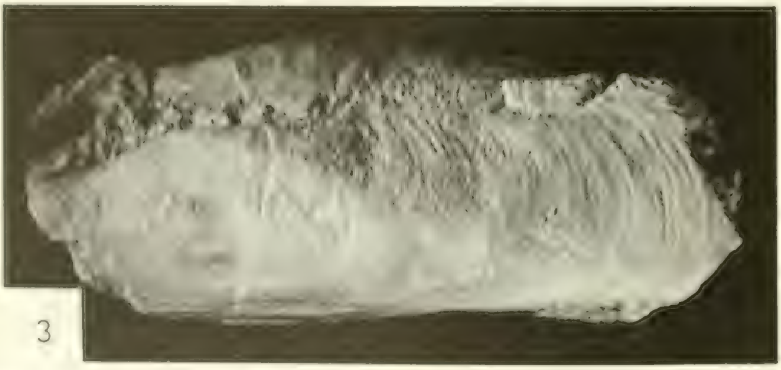

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PLATE 34

All figures are ×2.

Figs. 1-3. *Modiolopsis modiolaris* (Conrad) ....p. 127

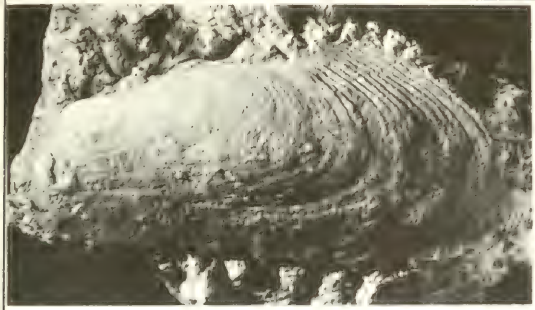
1. YPM 26020, Loc. 149 (A-6455).
2. YPM 26021, Loc. 203 (A-6301), latex impression.
3. YPM 26022, Loc. 186 (A-6323).

PLATE 35

All figures are ×2.

Figs. 1-4. *Modiolopsis modiolaris* (Conrad) ....p. 127

1. YPM 26023, Loc. 147 (A-6453).
2. YPM 26024, Loc. 125 (A-6433), possibly another species (cf. *M. concentrica*).
3. YPM 26025, Loc. 87 (A-6404).
4. YPM 26026, Loc. 203 (A-6302), showing shape variation resulting from tectonic distortion.



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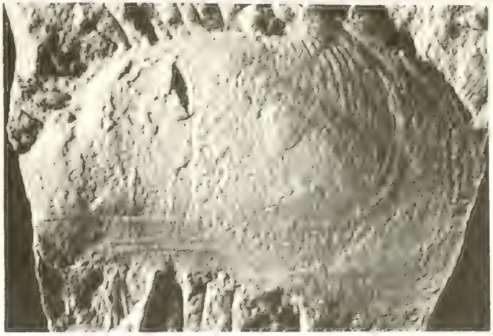

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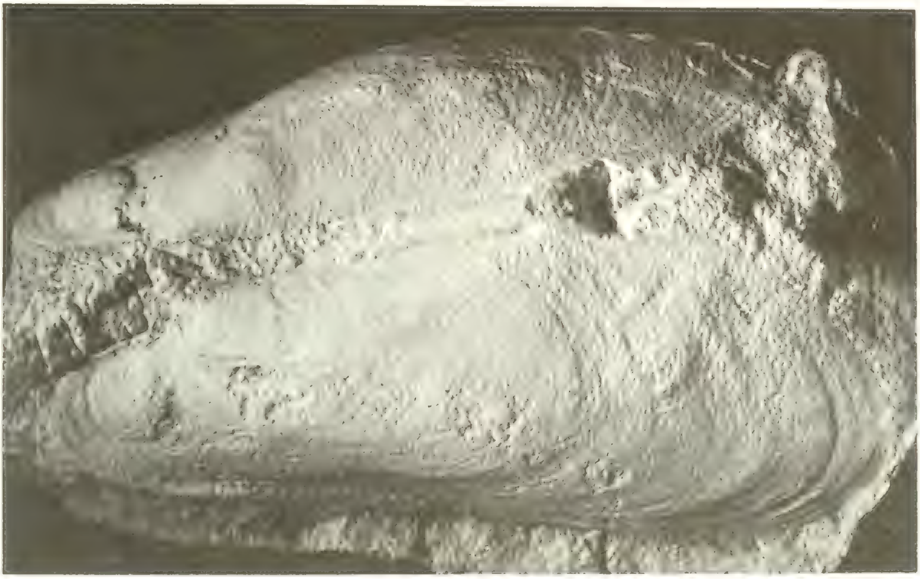

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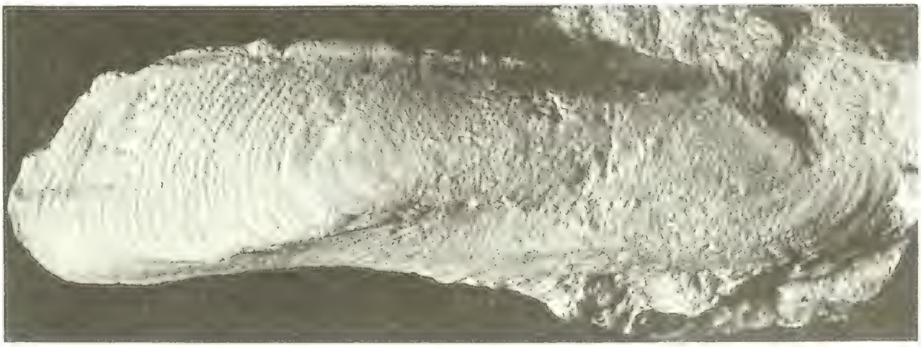

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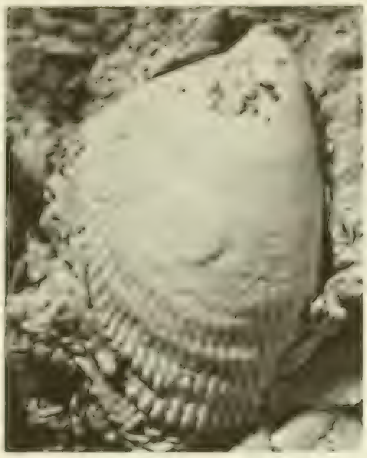

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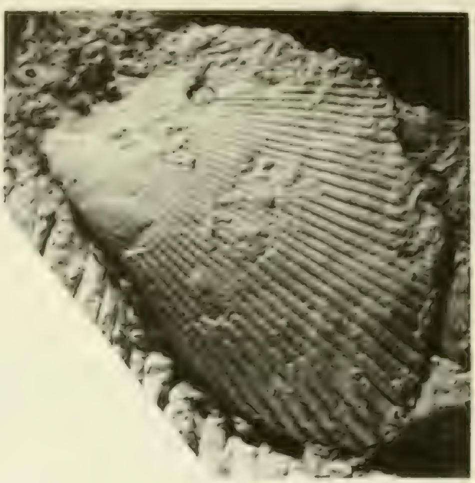

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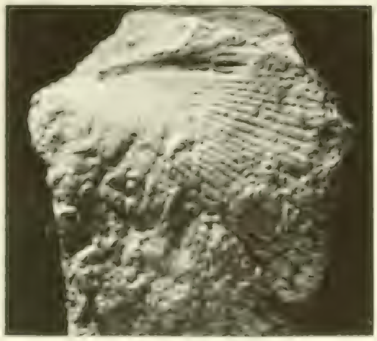

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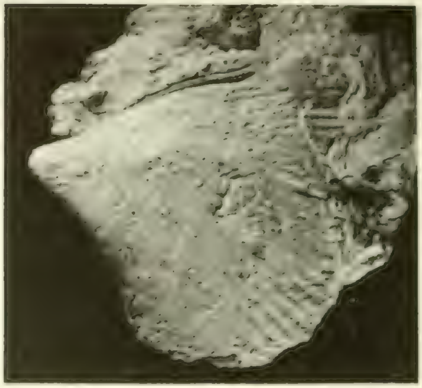

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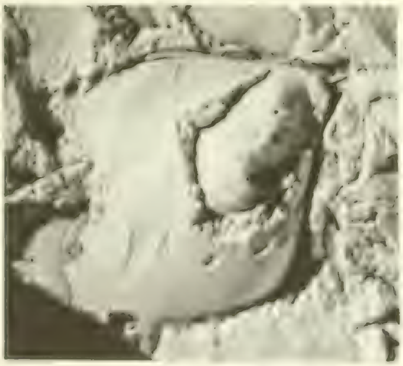

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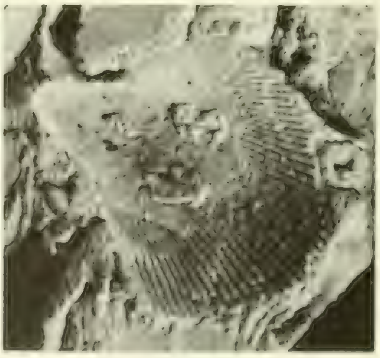


6

PLATE 36

All figures are ×2.

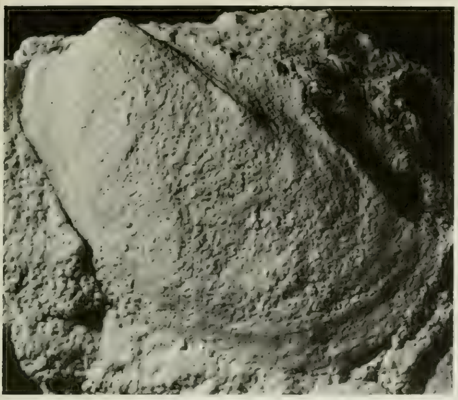
Figs. 1-6. *Ambonychia radiata* Hall . . . . .p. 117

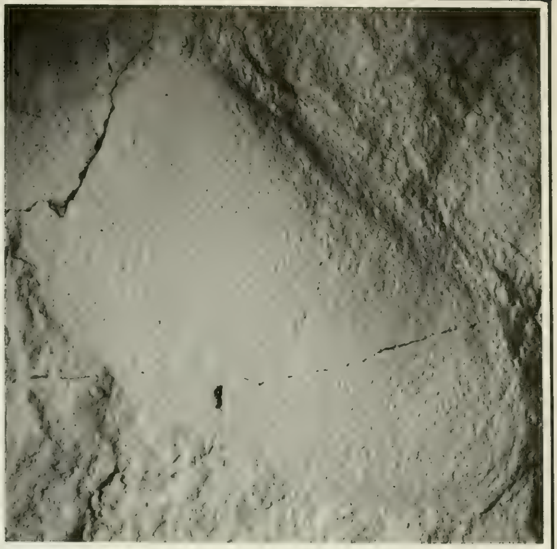
1. YPM 26027, Loc. 62 (H) (A-6382), showing striated ligament.
2. YPM 26028, Loc. 77-A (A-6397).
3. YPM 26029, Loc. 82 (A-6400), showing posterior lateral teeth.
4. YPM 26030, Loc. 37 (A-6359).
5. YPM 26031, Loc. 75 (A-6395), internal mold (natural) showing impression of cardinal and lateral teeth and part of posterior adductor muscle scar.
6. YPM 26031, external mold (natural) of fig. 5. Lighting from bottom.

PLATE 37

All figures are ×2 except figs. 2, 3 (×1).

Figs. 1-3. *Cyrtodonta?* ....p. 129
    1. YPM 26032, Loc. 167 (A-6467).
    2. YPM 26033, Loc. 167 (A-6467).
    3. YPM 26034, Loc. 167 (A-6467).
Figs. 4-5. *Ambonychia praecursa* (Ulrich) ....p. 118
    4. YPM 26035, Loc. 203 (A-6302).
    5. YPM 26036, Loc. 203 (A-6303).





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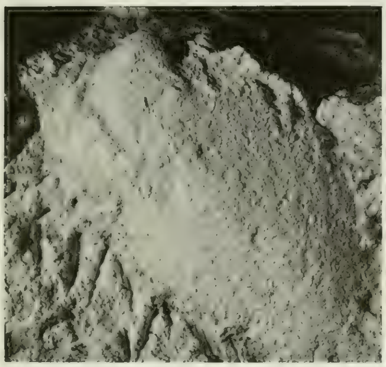

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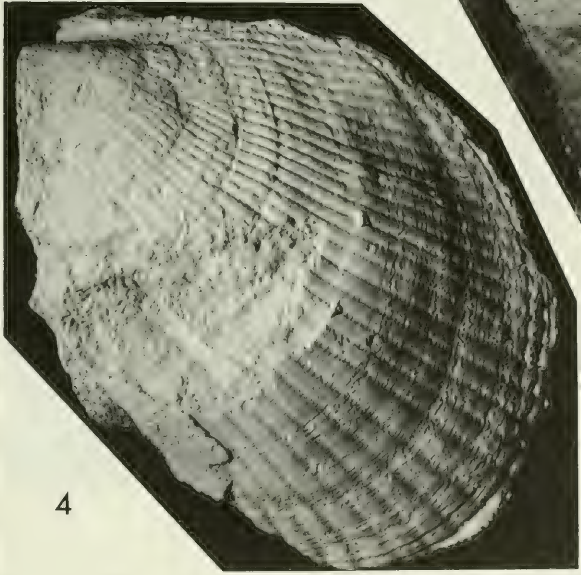

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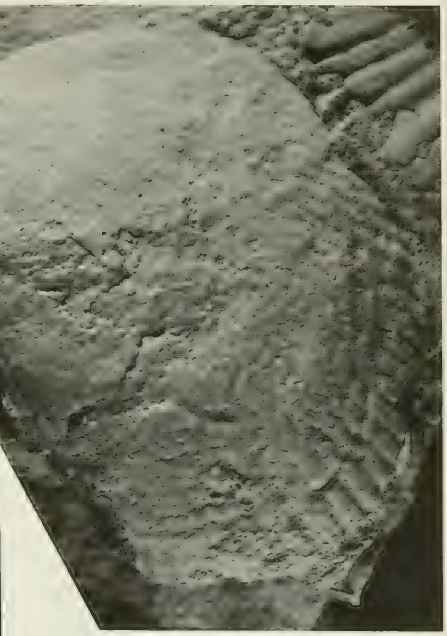

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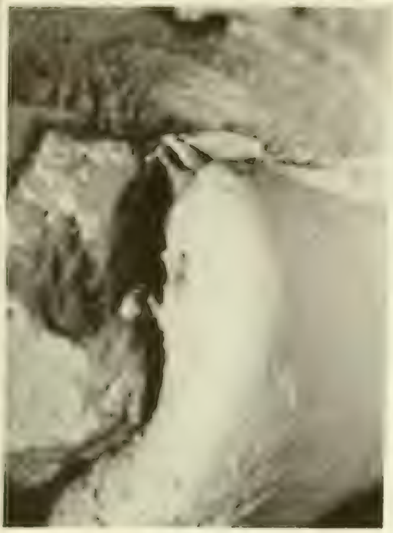

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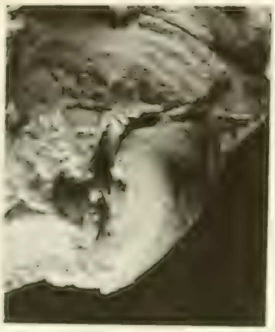

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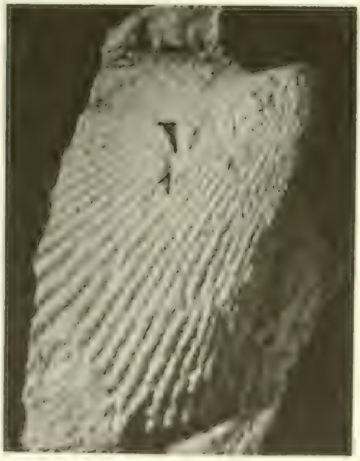

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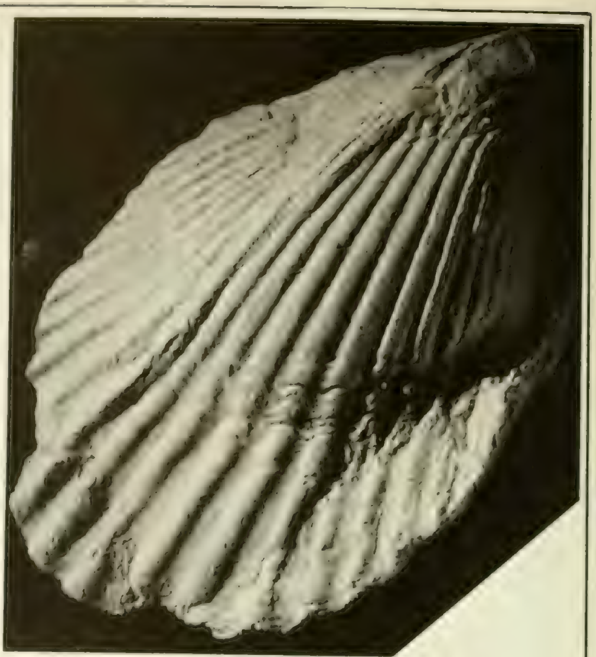

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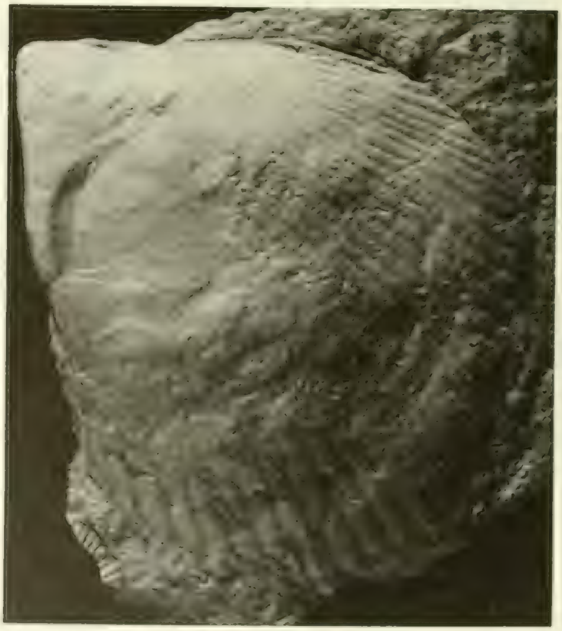

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PLATE 38

All figures are ×2 except fig. 1 (×4).

Figs. 1-2, 4-5. *Ambonychia praecursa* (Ulrich) .... p. 118

1. YPM 26037, Loc. 87 (A-6404), internal mold (natural) showing impression of cardinal dentition.
2. YPM 26037, same as fig. 1 only lower magnification.
4. YPM 26039, Loc. 177 (A-6476).
5. YPM 26040, Loc. 75 (A-6395), showing impression of lateral teeth confined to posterior end of hinge line.

Fig. 3. ?*Ambonychia byrnesi* (Ulrich) .... p. 123

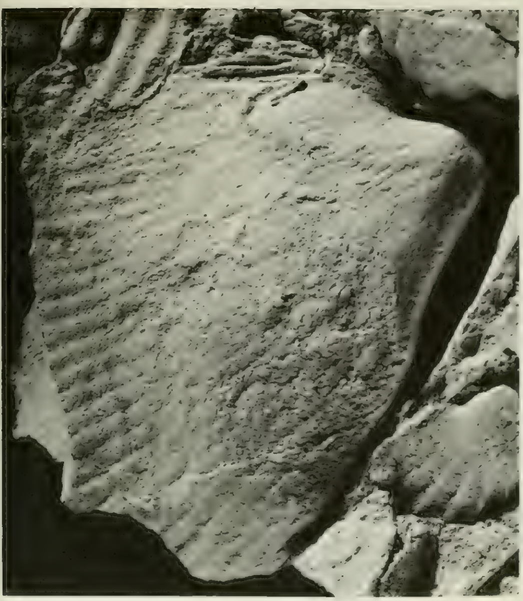
3. YPM 26038, Loc. 75 (A-6395).

PLATE 39

All figures are ×2.

Figs. 1-4. *Ambonychia praecursa* (Ulrich) ....p. 118

1. YPM 26041, Loc. 93 (A-6409), showing impression of posterior lateral teeth.
2. YPM 26042, Loc. 203 (A-6306), prominent byssal gap.
3. YPM 26043, Loc. 203 (A-6303).
4. YPM 26044, Loc. 203 (A-6303).



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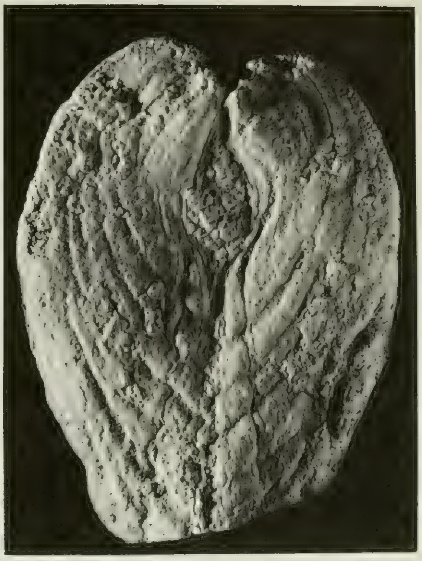

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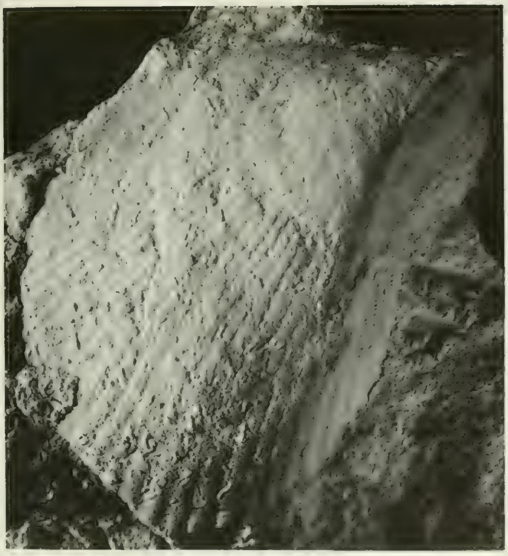

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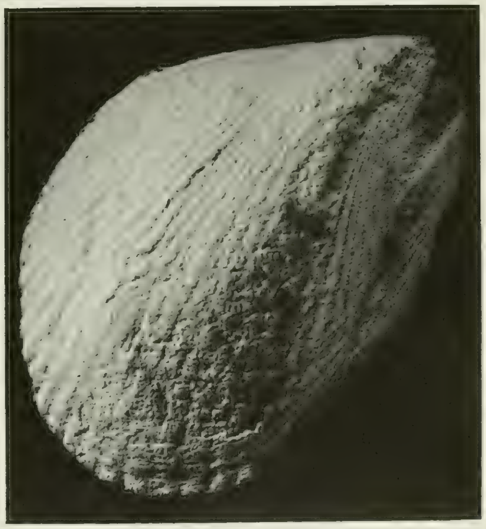

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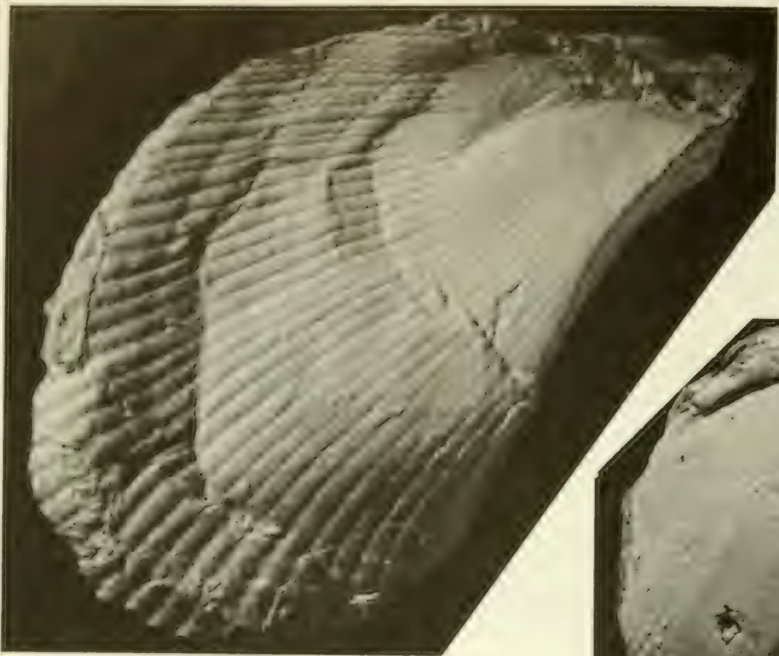
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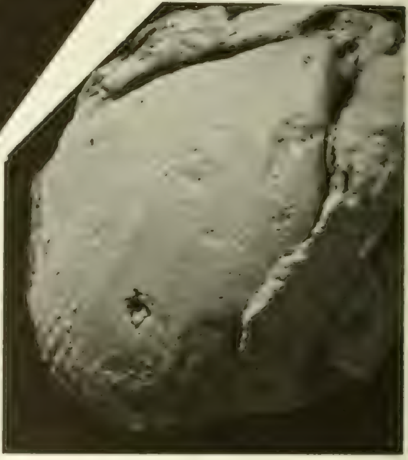
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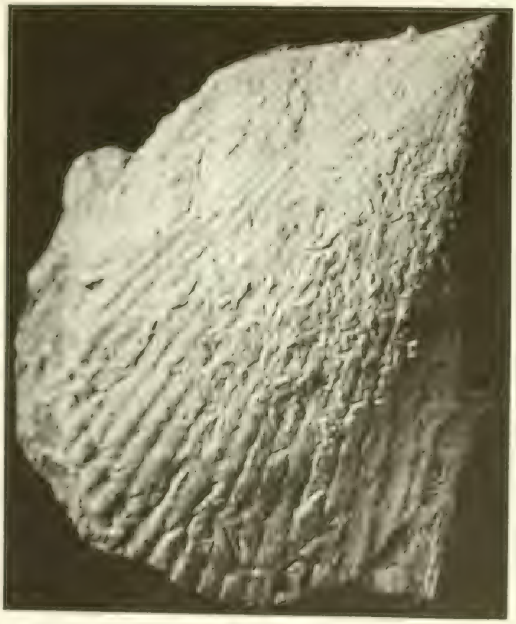
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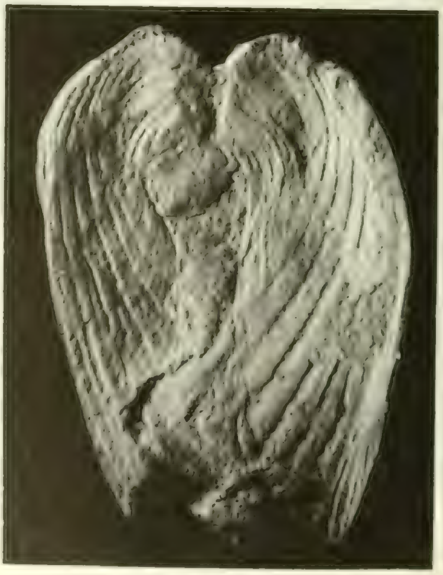
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PLATE 40

All figures are ×2.

Figs. 1-4. *Ambonychia praecursa* (Ulrich) . . . . p. 118

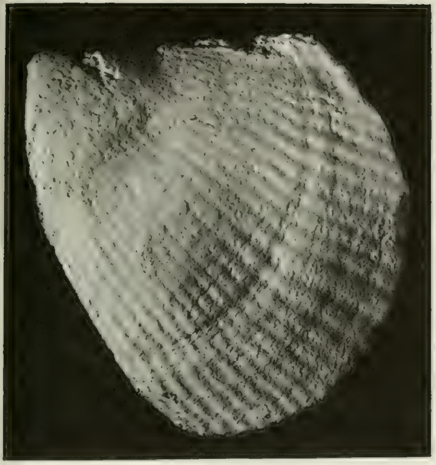
1. YPM 26045, Loc. 75 (A-6395).
2. YPM 26046, Loc. 203 (A-6303).
3. YPM 26047, Loc. 203 (A-886).
4. YPM 26048, Loc. 203 (A-6301).

PLATE 41

All figures are ×2.

Figs. 1-3. *Ambonychia praecursa* (Ulrich) .... p. 118

1. YPM 26049, Loc. 203 (A-6302).
2. YPM 26050, Loc. 75 (A-6395), bifurcation of some ribs near the hinge line.
3. YPM 26051, Loc. 75 (A-6395).



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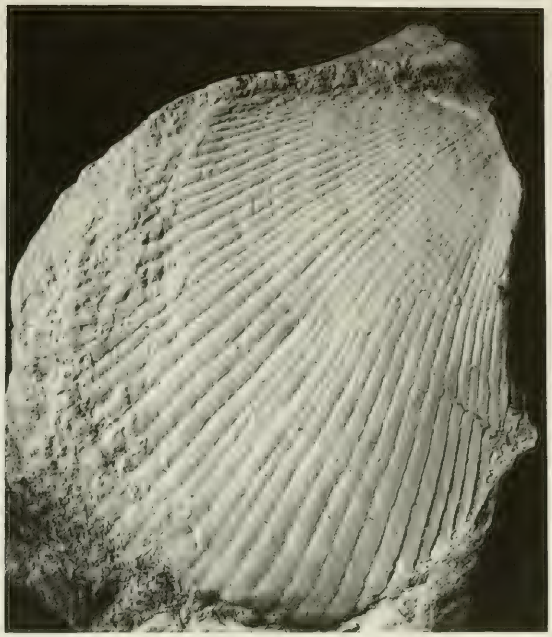

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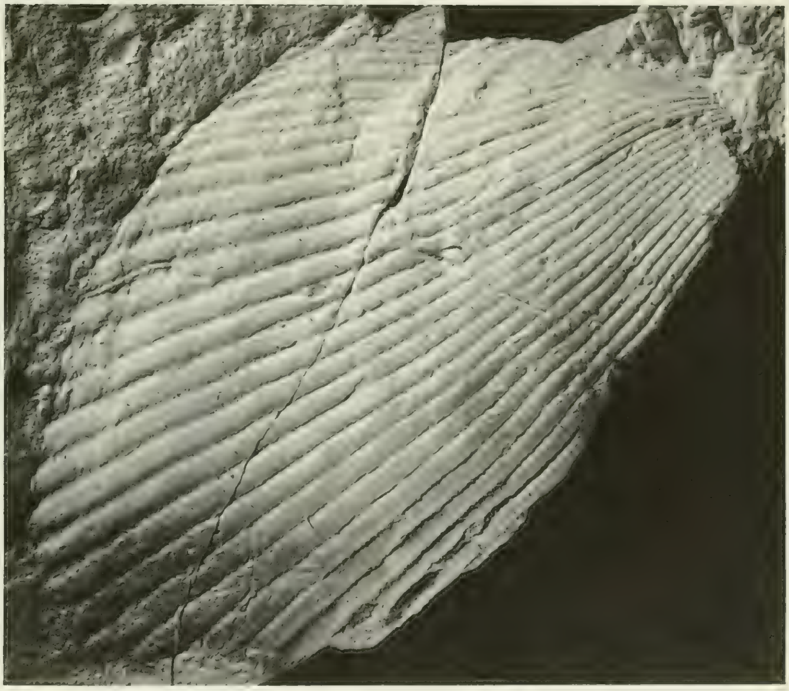

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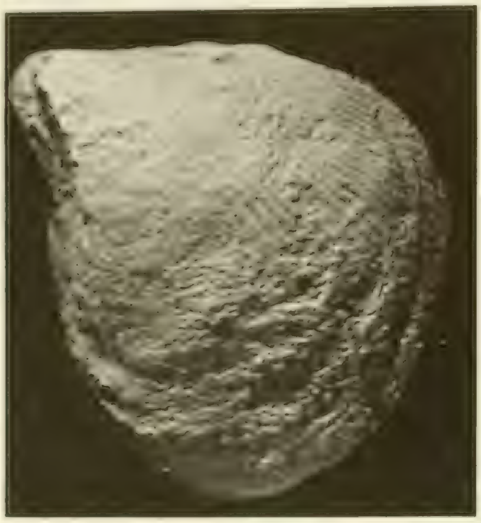

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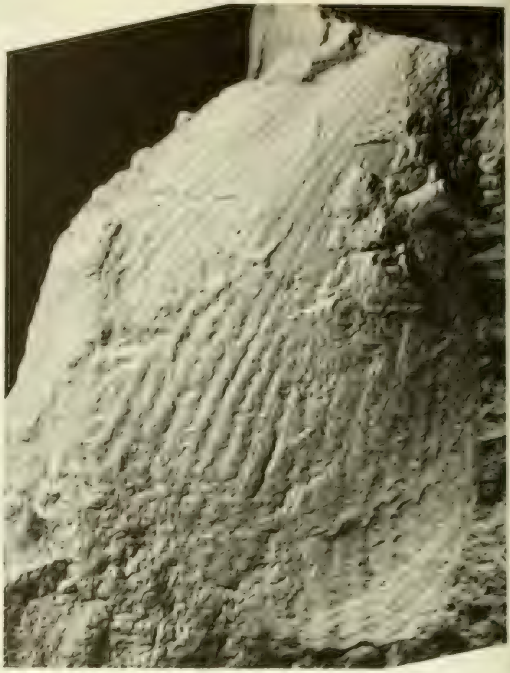

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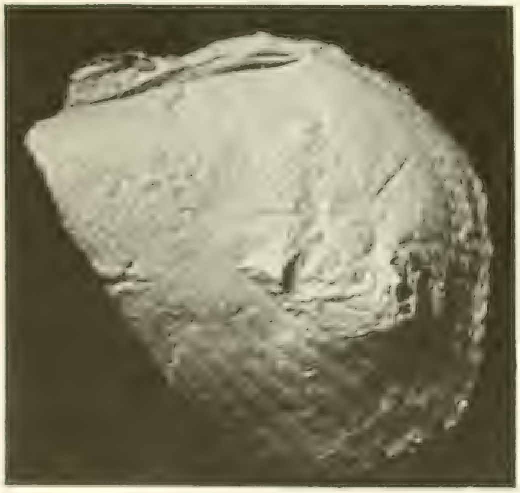

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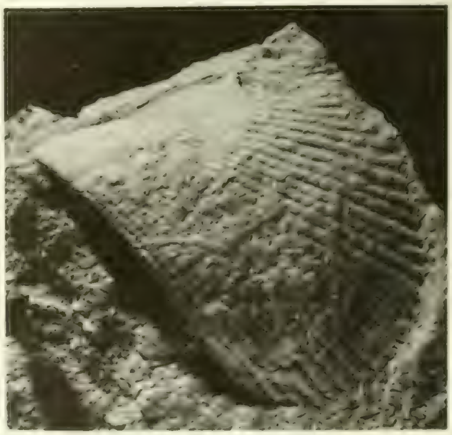

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PLATE 42

All figures are ×2.

Figs. 1-2. *Ambonychia cultrata* (Ulrich) ....p. 122

1. YPM 26052, Loc. 145 (A-6452).
2. YPM 26053, Loc. 152 (A-6458), showing impression of longitudinally striated ligament.

Figs. 3-4. *Ambonychia praecursa* (Ulrich) ....p. 118

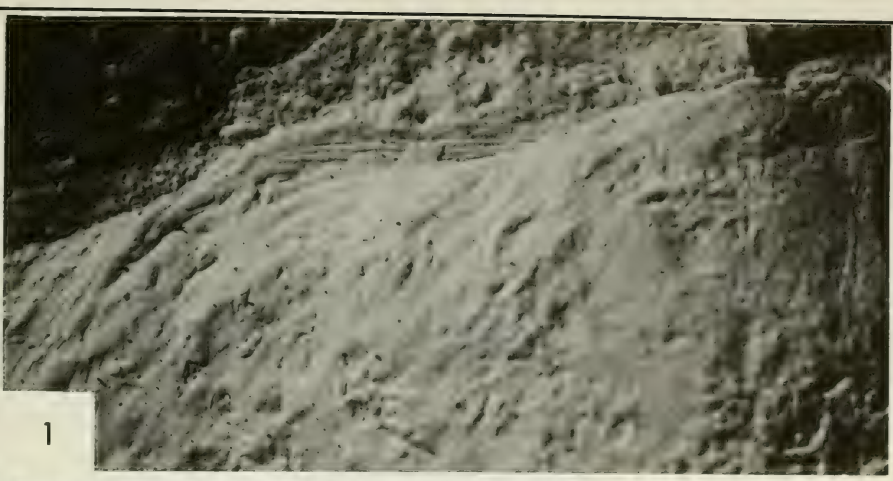
3. YPM 26054, Loc. 203 (A-6308).
4. YPM 26055, Loc. 203 (A-6303).

PLATE 43

All figures are ×2 except fig. 1 (×4), fig. 4 (×1).

Figs. 1-4. *Ambonychia cultrata* (Ulrich) ....p. 122

1. YPM 26056, Loc. 141 (A-6448), impression of longitudinally striated ligament.
2. YPM 26056, same as fig. 1 only lower magnification.
3. YPM 26057, Loc. 141 (A-6448), impression of striated ligament.
4. YPM 26058, Loc. 141 (A-6448).



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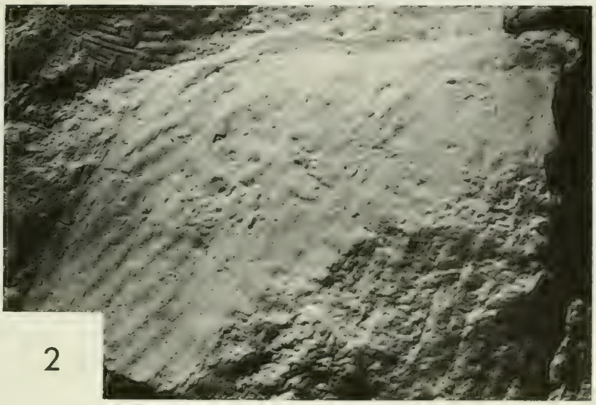

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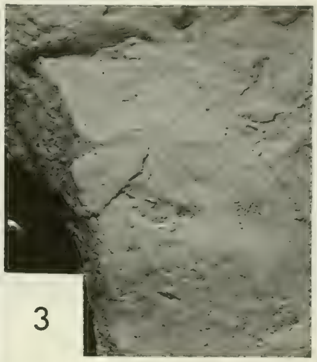

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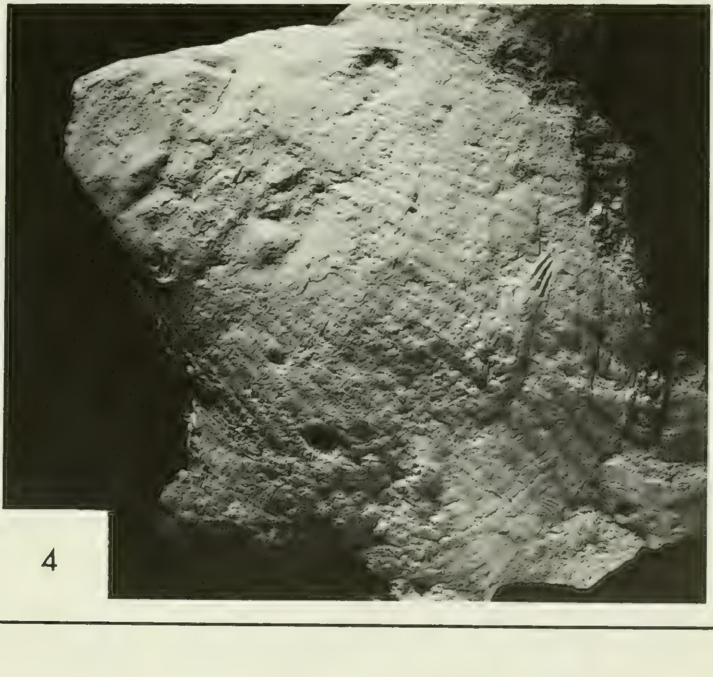

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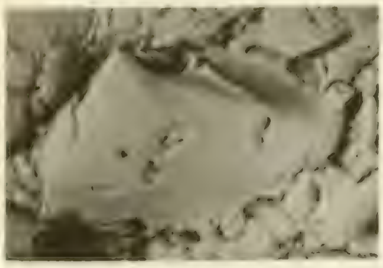

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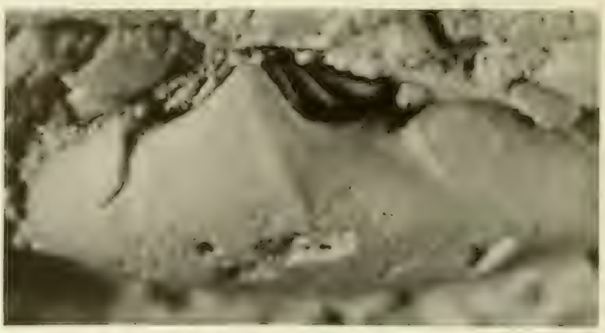

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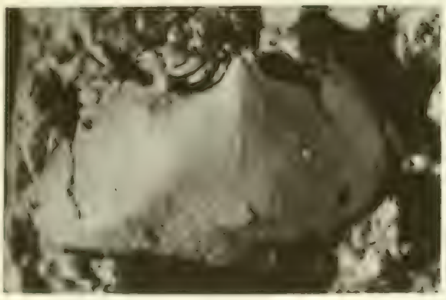

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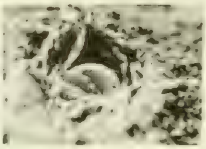

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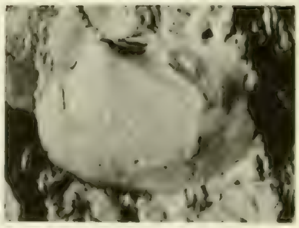

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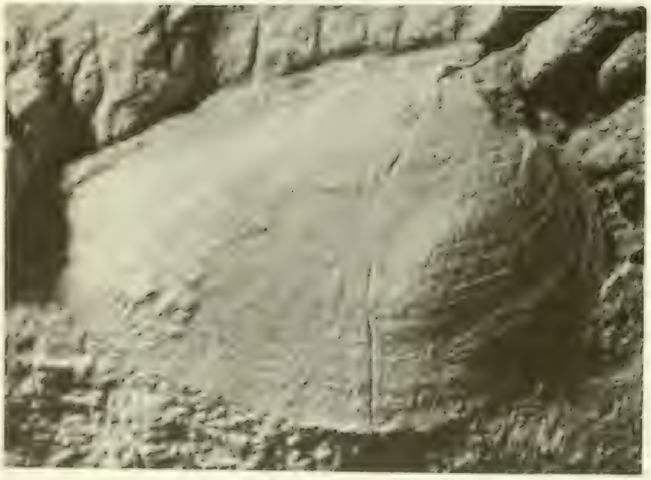

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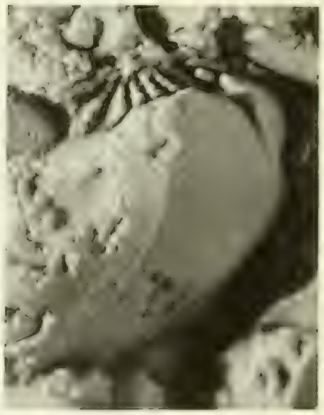

7

PLATE 44

All figures are ×4 except figs. 1, 5 (×2).

Figs. 1-7. *Lyrodesma poststriatum* (Emmons) .... p. 132

1. YPM 26059, Loc. 37 (A-6359).
2. YPM 26059, same specimen as fig. 1 only higher magnification showing impression of adductor and pedal muscle scars and prominent schizodont teeth.
3. YPM 26060, Loc. 97 (11) (A-6413).
4. YPM 26061, Loc. 77-A (A-6397), showing impression of well-marked longitudinal striae on each tooth.
5. YPM 26062, Loc. 37 (A-6359), showing impression of pallial line with distinct impression of a small, posteroventral pallial sinus.
6. YPM 26063, Loc. 149 (A-6455), showing impression of coarse radial ribs at posterodorsal edge of shell.
7. YPM 26064, Loc. 37 (A-6359).

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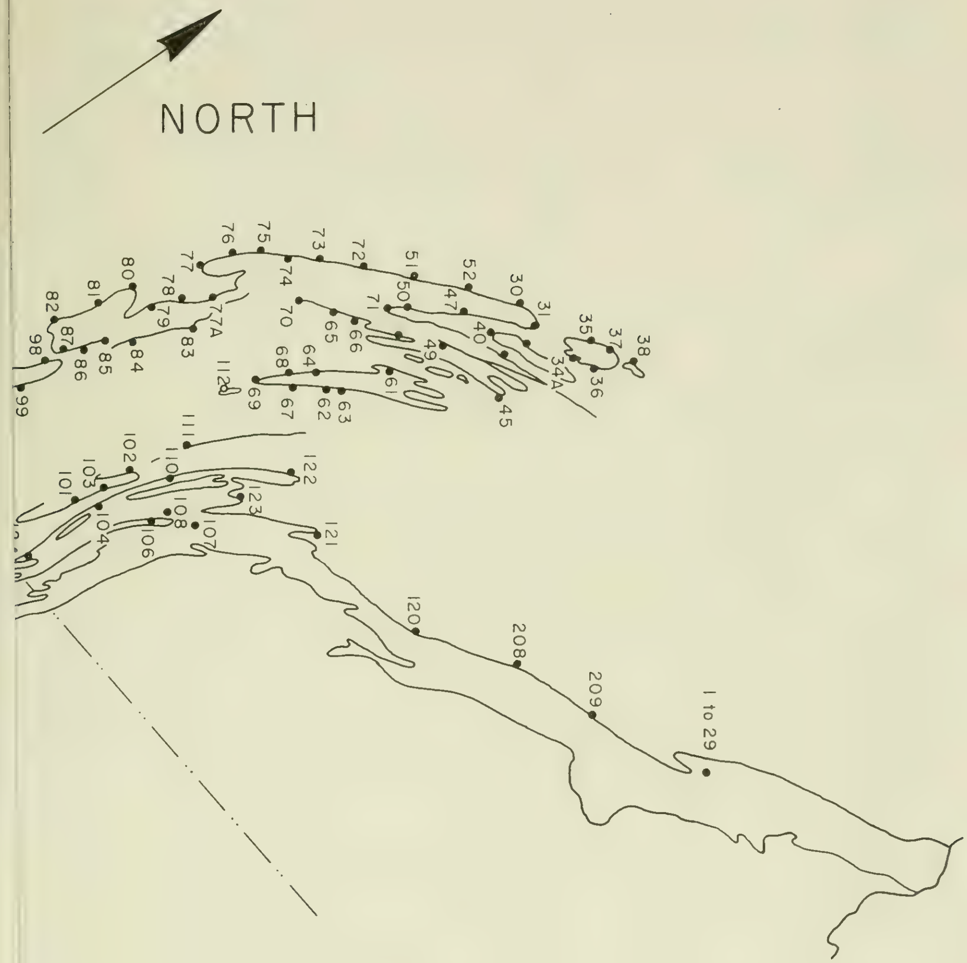
NORTH
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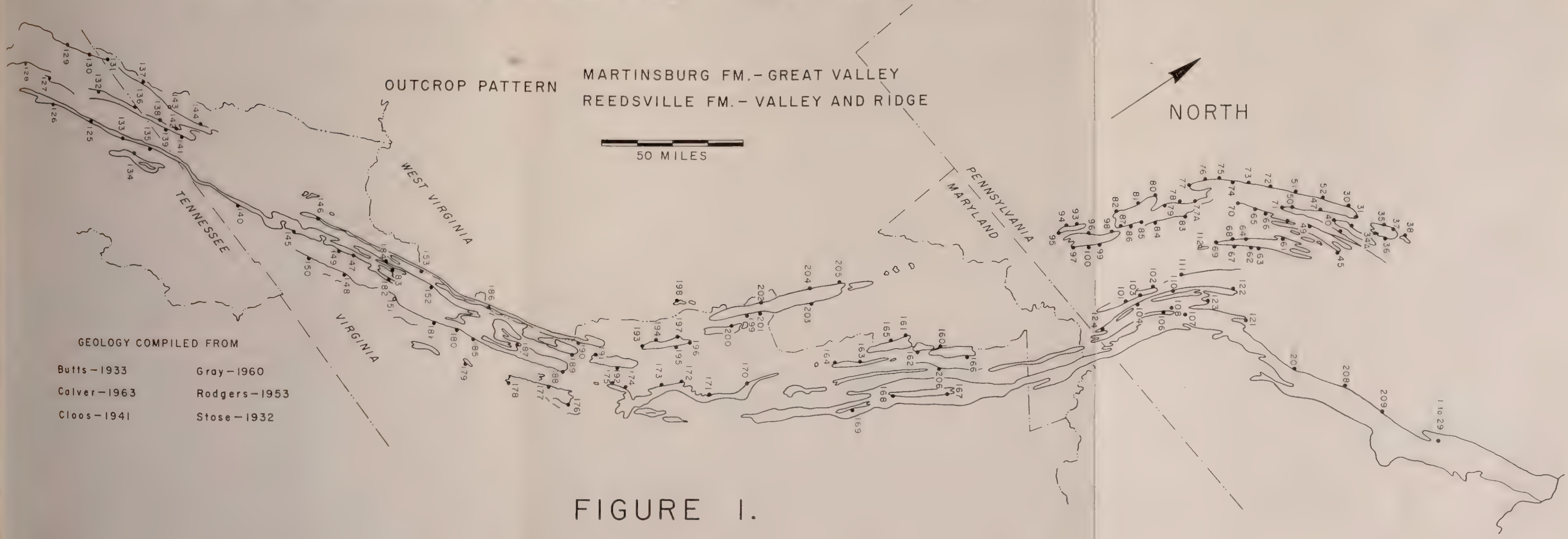
UPPER ORDOVICIAN LOCALITIES — CENTRAL APPALACHIANS


OUTCROP PATTERN
MARTINSBURG FM. – GREAT VALLEY
REEDSVILLE FM. – VALLEY AND RIDGE
50 MILES
NORTH
TENNESSEE
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
MARYLAND
1 to 29
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209
121
122
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GEOLOGY COMPILED FROM

Butts – 1933
Calver – 1963
Cloos – 1941
Gray – 1960
Rodgers – 1953
Stose – 1932

FIGURE I.

SOUTH

– VIRGINIA

PETERS MT.— POTTS MT.
CATAWBA MT.—WOLF CREEK MT
RICH MT.—EAST RIVER MT.
BIG WALKER MT.—CLINCH MT

TENNESSEE

CUMBERLAND MT.
POWELL MT.
CLINCH MT.

BRACHIOPODA

Lingula?
Orthorhynchula linneyi
Rafinesquina "alternata"
Sowerbyella (Sowerbyella) sericea
Hebertella sinuata
Onniella multisecta
Zygospira modesta
Zygospira recurvirostra

BRYOZOA

Dekayia
Hallopora
Batostomella
Monticulipora
Amplexopora

MOLLUSCA (BIVALVIA)

Ambonychia radiata
Ambonychia cultrata
Ambonychia praecursa
-? Ambonychia byrnesi
Ischyrodonta? truncata
Lyrodesma poststriatum
Pterinea (Caritodens) demissa
Modiolopsis modiolaris
Tancrediopsis cuneata
Praenucula levata
Ctenodonta? pulchella

(GASTROPODA)

Plectonotus? sp
Bucania sp.
Ruedemannia? lirata
Loxoplocus (Lophospira) abbreviata
Loxoplocus (Lophospira) ventricosta
Loxoplocus (Lophospira) perangulata
Sinuopea?
Murchisonia?

TRILOBITA

Cryptolithus
Flexicalymene
Isotelus

CRINOIDEA

Crinoid columnals

UPPER ORDOVIC
OF
CENTRAL A

PALINSPASTI
(AFTER DEN

ADDITIONAL SOURCES
FOR MEASURED
GEOLOGIC SECTIONS

BASSLER - 1919
BRENT - 1960
BUTTS - 1941
COOPER, B.N. - 1944
GRABAU - 1913
HOROWITZ - 1965
MILLER & BROSGE - 1954
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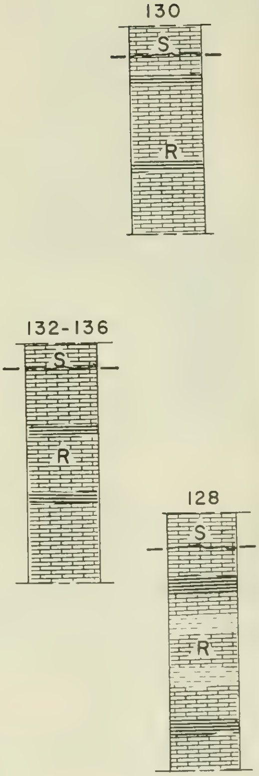
SECRIST & EVITT - 1943
SWARTZ - 1957
WILLARD - 1943
WOODWARD - 1951

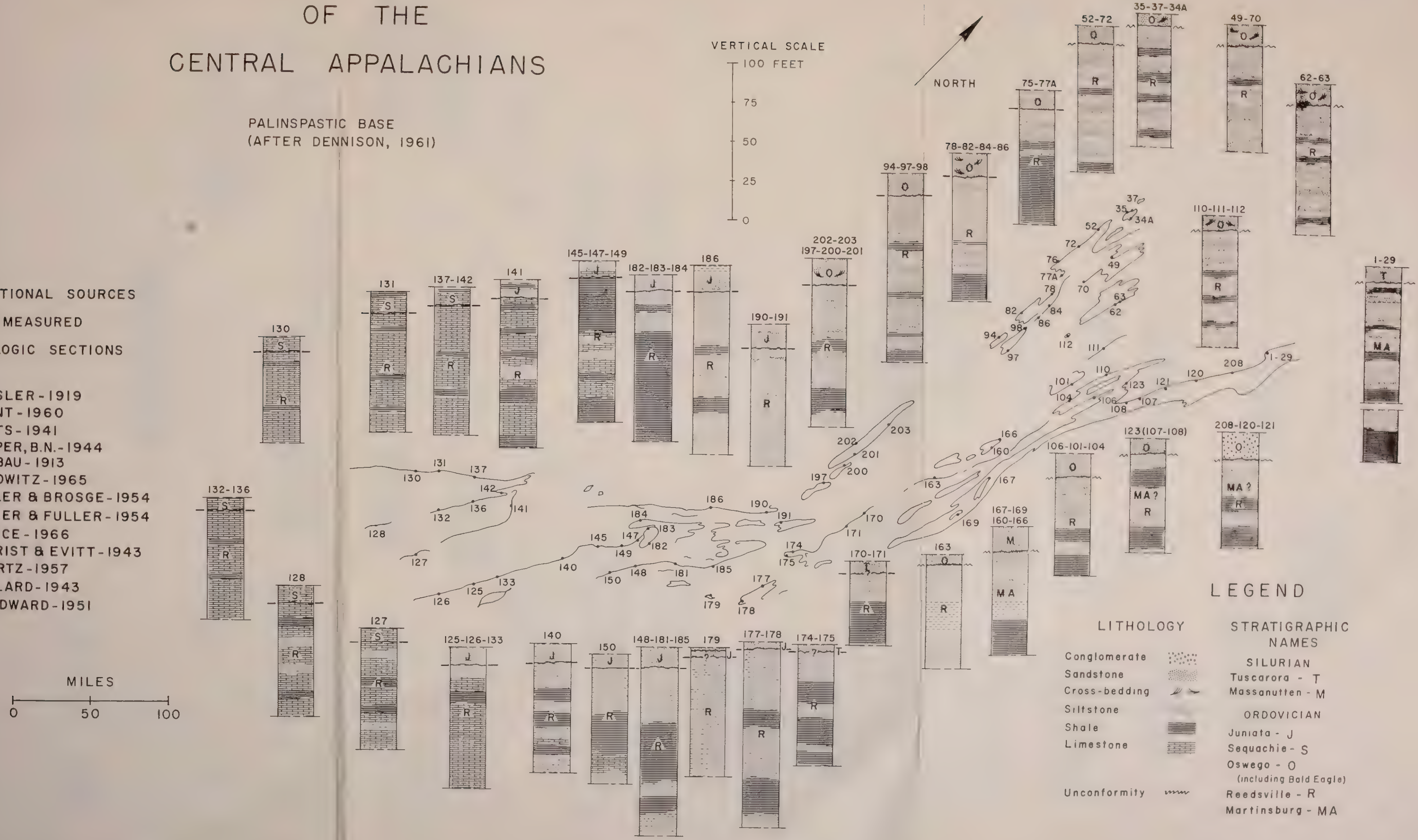


MILES
0 50 100

NORTH		PENNSYLVANIA — MARYLAND		WEST VIRGINIA — VIRGINIA			TENNESSEE	SOUTH
	GREAT VALLEY EASTERN PA SHOCHARY RIDGE	GREAT VALLEY—PA—MD TUSCARORA MT. KITTATINY—BEARPOND MT. SHADE and COVE MTS.	RACCOON MT. NITTANY MT. BALD EAGLE MT. JACKS MT — TUSSY MT WILLS MT. — EVITTS MT.	MASSANUTTEN and NORTH (N) MTS	NORTH FORK MT. JACK MT.—NORTH MT. (So) MIDDLE MT.—RICHPATCH MT.	PETERS MT.— POTTS MT. CATAWBA MT.—WOLF CREEK MT. RICH MT.—EAST RIVER MT. BIG WALKER MT—CLINCH MT	CUMBERLAND MT. POWELL MT. CLINCH MT.	
LOCALITY	1 2 3 4 9 11 12 15 16 17 18 19 22 23 24 25 26 27	208 120 121 89 127 122 123 109 108 106 105 104 124 111 110 103 101	38 37 36 35 34+34A 32 33 42 30 31 39+39A 43 44 52 47 45 48 49 207 50 60 72 71 66 63 62 64 68 70 73 75 77+77A 112 78 83 79 84 86 81 82 87 98 92 96 99 100 97 93 94 95	166 160 206 162 161 165 163 164 167 168 169	205 204 203 202 201 199 200 170 171 172 173 174 175 198 196 195 197 194 193 192 191	190 189 188 177 187 178 186 185 180 179 181 152 153 184 183 182 151 147 148 149 150 145 140	144 143 142 141 137 138 139 131 136 135 133 125 132 130 129 127 126 128	
BRACHIOPODA								**BRACHIOPODA**
Lingula?			1 3 2 2 3 4 3 2 2 2 2 2 3	2	2 5 5 2 2 5 2 5 5 3 4 4 2 5 5 5	4 5 5 5 4 3 1 5 4 5 4 2 1	1	Lingula?
Orthorhynchula linneyi		1 1 1 4 1 2	1 5 5 4 5 1 3 4 4 3 4 3 5 2 5 5 3 2	1 3 4	5 5 5 5 5 3 1 4 5 2 3 1 1	4 1 2 1 3 5 2 5 2 2 2 5 5 5 4 5 1 1	1 1 1 1 1 1	Orthorhynchula linneyi
Rafinesquina "alternata"	2 1 3 1 1 1	3 5 3 5 4 4	5 5 2 3 1 1 2 5 5 1 1 2 4 5 1 5 2 5 5	3 2 1 3 4	2 1 2 2 1	3 5 1 3	1 1 1 1 2 1 3 1 3	Rafinesquina "alternata"
Sowerbyella (Sowerbyella) sericea	1 1 2 5 5 4 5 4 5 3 5 5 5 5 3 1	1 1 5 4 4 4 2	2 1 1 3 1 1 5 1 1 1 1 2 1 5 1 1 1 2 2 1 1 2 5	1 2 2		2		Sowerbyella (Sowerbyella) sericea
Hebertella sinuata						3 5 3 4 4 5 2 2 5 5 5 5 2	4 3 2 2 4 5 4 5 1 1 1	Hebertella sinuata
Onniella multisecta	2 3 4 2 3 1 5 5 4 5 5 1 2 2 5 5 5	2 3 1 5 3 2	5 1 5 5 2 4 5 2 5 4 5 3 3 1 1 1 1 1 2 4 3 3 2 3 1	1 1 1 1 1 1 1		1		Onniella multisecta
Zygospira modesta	1 1	1 2 2 1 1 2 1 1 2 4	5 1 2 1 1 5 1 1 1 2 1 1 3 1	5 1 1 1	1 1 1	1		Zygospira modesta
Zygospira recurvirostra						1 2 1 1 3 2 2 3 2 1 4 5 5 1	3 5 1 5 5 2 3 5 4 3 2 3 3	Zygospira recurvirostra
BRYOZOA								**BRYOZOA**
Dekayia					4 3 2	5 4 1 1 1 1	3 2 5 1 1 3	Dekayia
Hallopora		2	1 5 1 5 1 1 2			5 1 5 1	5 1 2 3 5 2 2	Hallopora
Batostomella						1 5	5 4	Batostomella
Monticulipora							5 5 1 1 1	Monticulipora
Amplexopora							1 7 5	Amplexopora
MOLLUSCA (BIVALVIA)								**MOLLUSCA (BIVALVIA)**
Ambonychia radiata		1 1 1 1 1	1 1 1 1 1 4 1 1 1 1 3 1 1	1 1		1 1 1	1 1 1 1 1 1 1	Ambonychia radiata
Ambonychia cultrata						1 5 1 2 3 2 4 2 4 2	1 5 1 2 1 1 1	Ambonychia cultrata
Ambonychia praecursa		4 3	1 1 4 3 5 5 2 4 3 3 1 2 2	1 2 1	3 5 5 2 4 5 3 4 5 3 1 1 3 4	2 2 1 3 1 3 3 5 5 1 2 5 2 2 1 1		Ambonychia praecursa
?Ambonychia byrnesi			2					?Ambonychia byrnesi
Ischyrodonta? truncata		2 2	1 1 2 1 5 3 4 2 4 2 3 1 3 3 2 4 1		1 2 2 2 4 5 5 1 1 2 2 1	4 4 4 4 1 2 3 4 3 2 3 3 1 5	3 1 1 1 1 1 1	Ischyrodonta? truncata
Lyrodesma poststriatum		3 1	5 2 1 3 1 1 1 1 5			1		Lyrodesma poststriatum
Pterinea (Caritodens) demissa		1	1 1 1 1 1 1 1 1	1 1	1 2 1 1	1 1 1 1 1 1 5 2 5 5 1	2 3 1 2 2 1 2 1	Pterinea (Caritodens) demissa
Modiolopsis modiolaris		1 1 2	1 1 1 1 1 1 3 5 4 4 3 3	1 3 3 1	2 4 3 3 3 5 2 2 1 4 4 5 2 4 1	3 2 1 5 1 1 3 5 1 3 5 1 2 3 5 5 2 4 2 5 2	1 1 4 1 1 1 1 1 1 3 2 1 2	Modiolopsis modiolaris
Tancrediopsis cuneata		1	1 5 1 5 5 4 3 4 2 5 2 3 4 5 5 3 3 5	1	1 4 5 5 5 5 1 1 4 3 5 5 4 5 5	5 5 5 1 3 4 1 3 5 3 3 5 4		Tancrediopsis cuneata
Praenucula levata			3 1 1 2 1 1 1					Praenucula levata
Ctenodonta? pulchella			4 3 4 1					Ctenodonta? pulchella
(GASTROPODA)								**(GASTROPODA)**
Plectonotus? sp		2	5 2 1 1 2 3 1 5 5 5 5 4 3 5 1 2 4	5 5	2 5 5 2 5 5 4 2 4 5 2 4 3 5 5	5 5 5 5 5 2 5 2 2 5 3		Plectonotus? sp
Bucania sp		1 1 1	2 1 1 1 1 1 1 1 1 1 1		1 1 1	1 1 2 1 1 1		Bucania sp.
Ruedemannia? lirata		1	1 2 1	1				Ruedemannia? lirata
Loxoplocus (Lophospira) abbreviata		3 3 1 2	1 1	5 5	1 3 2	2 1 1 1		Loxoplocus (Lophospira) abbreviata
Loxoplocus (Lophospira) ventricosta		1 1 1	2 1	3 2				Loxoplocus (Lophospira) ventricosta
Loxoplocus (Lophospira) perangulata				1	3	4 2	3	Loxoplocus (Lophospira) perangulata
Sinuopea?		1 2 1 1 2	3 2 2	4 4 2	2			Sinuopea?
Murchisonia?							2 2 3	Murchisonia?
TRILOBITA								**TRILOBITA**
Cryptolithus	1	1 5 2 1 2 1 2	1 1					Cryptolithus.
Flexicalymene		1 1 1 1 2	1 1 2 1 1 1 1					Flexicalymene
Isotelus		1	1					Isotelus
CRINOIDEA								**CRINOIDEA**
Crinoid columnals	1 1 1 1 1 2	2 5 4 5 5 1 5 3 5 5 5 1 1 2	1 2 5 5 3 4 3 5 5 5 4 5 3 1 5 1 5 1 1 3 5 5 3 2 5 5 5 5 3 5 5 5	1 1 1 1		1		Crinoid columnals

TABLE 3 — Distribution of central Appalachian Upper Ordovician faunas

UPPER ORDOVICIAN STRATIGRAPHY OF THE CENTRAL APPALACHIANS


PALINSPASTIC BASE
(AFTER DENNISON, 1961)
VERTICAL SCALE
100 FEET
75
50
25
0
NORTH
MILES
0
50
100
130
131
137-142
141
145-147-149
182-183-184
186
190-191
202-203
197-200-201
94-97-98
78-82-84-86
75-77A
52-72
35-37-34A
49-70
62-63
110-111-112
1-29
132-136
128
127
125-126-133
140
150
148-181-185
179
177-178
174-175
170-171
163
167-169
160-166
106-101-104
123(107-108)
208-120-121
LEGEND
LITHOLOGY
Conglomerate
Sandstone
Cross-bedding
Siltstone
Shale
Limestone
Unconformity
STRATIGRAPHIC NAMES
SILURIAN
Tuscarora - T
Massanutten - M
ORDOVICIAN
Juniata - J
Sequachie - S
Oswego - O
(including Bald Eagle)
Reedsville - R
Martinsburg - MA

ADDITIONAL SOURCES FOR MEASURED GEOLOGIC SECTIONS

BASSLER - 1919
BRENT - 1960
BUTTS - 1941
COOPER, B.N. - 1944
GRABAU - 1913
HOROWITZ - 1965
MILLER & BROSGE - 1954
MILLER & FULLER - 1954
PIERCE - 1966
SECRIST & EVITT - 1943
SWARTZ - 1957
WILLARD - 1943
WOODWARD - 1951

FIGURE 5.

IAN STRATIGRAPHY

THE

PPALACHIANS

: BASE
NISON, 1961)

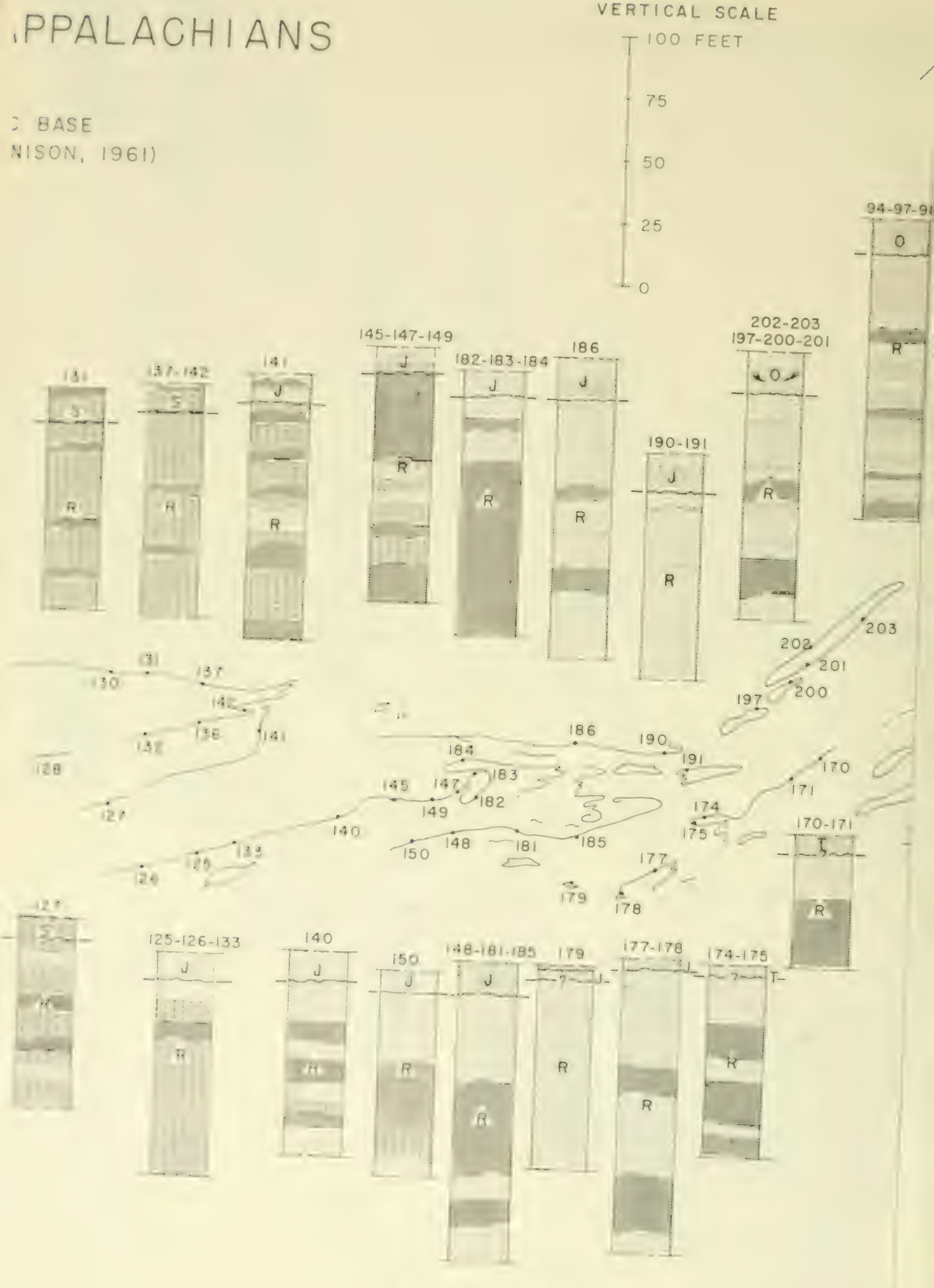
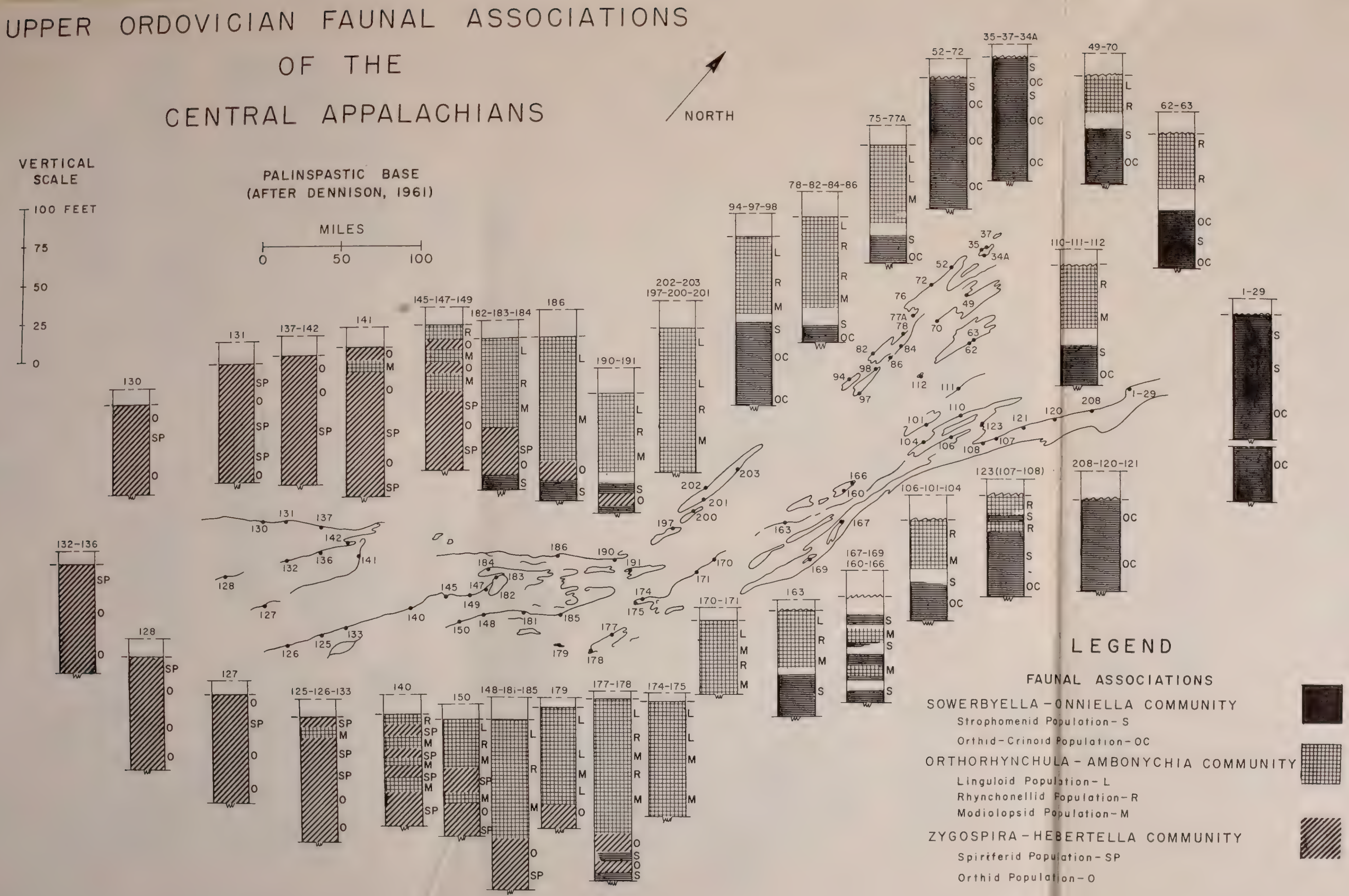

VERTICAL SCALE
100 FEET
75
50
25
0
94-97-91
O
R
202-203
197-200-201
O
R
145-147-149
J
R
182-183-184
J
R
186
J
R
190-191
J
R
131
S
R
137-142
S
R
141
J
R
203
202
201
200
197
131
130
137
142
136
141
132
128
127
186
190
191
184
183
145
147
182
149
140
150
148
181
185
170
171
174
175
177
179
178
133
126
124
170-171
T
R
127
S
R
125-126-133
J
R
140
J
R
150
J
R
148-181-185
J
R
179
?
J
R
177-178
J
R
174-175
?
T
R

FIGURE 5.


UPPER ORDOVICIAN FAUNAL ASSOCIATIONS OF THE CENTRAL APPALACHIANS

NORTH
VERTICAL SCALE
100 FEET
75
50
25
0
PALINSPASTIC BASE (AFTER DENNISON, 1961)
MILES
0
50
100
130
131
137-142
141
145-147-149
182-183-184
186
190-191
202-203 197-200-201
94-97-98
78-82-84-86
75-77A
52-72
35-37-34A
49-70
62-63
110-111-112
1-29
132-136
128
127
125-126-133
140
150
148-181-185
179
177-178
174-175
170-171
163
167-169 160-166
106-101-104
123(107-108)
208-120-121
LEGEND
FAUNAL ASSOCIATIONS
SOWERBYELLA-ONNIELLA COMMUNITY
Strophomenid Population-S
Orthid-Crinoid Population-OC
ORTHORHYNCHULA-AMBONYCHIA COMMUNITY
Linguloid Population-L
Rhynchonellid Population-R
Modiolopsid Population-M
ZYGOSPIRA-HEBERTELLA COMMUNITY
Spiriferid Population-SP
Orthid Population-O

FIGURE 6.

Stratigraphy and Paleontology of the Cloverly Formation (Lower Cretaceous) of the Bighorn Basin Area, Wyoming and Montana

John H. Ostrom

Bulletin 35

PEABODY MUSEUM
OF NATURAL HISTORY
YALE UNIVERSITY

Stratigraphy and Paleontology of the Cloverly Formation (Lower Cretaceous) of the Bighorn Basin Area, Wyoming and Montana

JOHN H. OSTROM

Peabody Museum of Natural History
and Department of Geology and
Geophysics, Yale University

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YALE UNIVERSITY
NEW HAVEN, CONNECTICUT

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    ?Family Titanosauridae 77
ORDER ORNITHISCHIA, SUBORDER ORNITHOPODA 85
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14. Titanosauridae?
15. Sauropoda?, *Camptosaurus dispar*, Amioidei
16. *Tenontosaurus tilletti*
17. *Tenontosaurus tilletti*
18. *Tenontosaurus tilletti*
19. *Tenontosaurus tilletti*
20. *Tenontosaurus tilletti*
21. *Tenontosaurus tilletti*
22. *Sauropelta edwardsi*
23. *Sauropelta edwardsi*
24. *Sauropelta edwardsi*
25. *Sauropelta edwardsi*
26. *Sauropelta edwardsi*
27. *Sauropelta edwardsi*

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1. Measured sections in the Cloverly-Shell Creek area
2. Measured sections in the Hyattville-Tensleep-Nowood Creek area
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ABSTRACT

The nonmarine strata of the Bighorn Basin, lying between the Late Jurassic Sundance Formation and the Early Cretaceous Thermopolis Shale, have been subdivided into three formal units: the Morrison, Cloverly and Sykes Mountain Formations. Application of these terms to actual outcropping rock units has been quite inconsistent, and considerable confusion and disagreement exist over formation boundary positions. Traverses around the periphery of the Bighorn Basin and across adjacent areas to the north, west and south established the existence of seven distinctive lithic units. These are: a lowermost, drab gray, calcareous claystone; a massive, brilliant white, quartz-chert sandstone (in the southern part of the Basin) ; a variegated gray-green or pink, calcareous claystone; a massive, black chert, coarse sandstone or conglomerate (in the northern part of the Basin) ; a drab gray to white or pastel-colored, bentonitic and noncalcareous claystone rich in chalcedonic and baritic concretions; a discontinuous series of coarse, yellow to ochre-colored, clay-rich, feldspathic channel sands; and a brightly variegated, noncalcareous, bentonitic claystone rich in polished, siliceous pebbles and cobbles ("gastroliths" of some authors). These seven units have been designated here by informal terms: Unit I to Unit VII. Units I through III are considered as the Morrison Formation. Units IV through VII correspond wholly or in part with the Pryor Conglomerate, Little Sheep Mudstone and Himes Mudstone Members of the Cloverly Formation, as that formation was defined by Moberly (1960). Units VI and VII and the lower sands (Unit VIII) of the overlying Sykes Mountain Formation correspond to the Cloverly Formation as it was defined by Darton in 1906. Some authors have applied the term Morrison to the entire nonmarine sequence and limited the Cloverly Formation to basal sands (Unit VIII) of Moberly's Sykes Mountain Formation. In order to provide a meaningful stratigraphic foundation for placement of the paleontologic collections obtained, the stratigraphic sections and terminology usage of previous workers are compared in detail with the informal lithic units recognized in this study.

Extensive collections of fossil vertebrate remains were made from Units V, VI and VII. The fauna, as presently known, is considerably less diverse than that of the Morrison Formation of other regions. It includes a new species of *Ceratodus* (*C. frazieri*), an indeterminate amioid, two baenoid turtles (*Naomichelys speciosa* Hay, 1908 and *Glyptops pervicax* Hay, 1908), a possible testudinid, indeterminate mesosuchian crocodilians, and several theropods (*Deinonychus antirrhopus* Ostrom, 1969; *Microvenator celer* [new genus and species]; an undefinable species of *Ornithomimus;* and an undefinable, but distinctive, large theropod. Also, of greatest abundance, are remains of a titanosaurid sauropod, a new genus and species of iguanodontid ornithopod (*Tenontosaurus tilletti*) and a new genus and species of acanthopholid ankylosaur (*Sauropelta edwardsi*). Despite extensive washing and sieving, no mammalian or other microfaunal remains were recovered.

The Cloverly fauna is totally distinct from that of the classical Morrison Formation. With the possible exception of the crocodilian remains, not a single Cloverly specimen is referable to a taxon presently known from the Morrison Formation. On the other hand, the few fragmentary vertebrate fossils that have been recovered from Units I, II and III in the study area are referable to well-established Morrison taxa. In addition, all specimens now known from the Cloverly Formation (Units V, VI and VII) appear to have closer affinities with Late Cretaceous taxa than with Morrison species. This may be explained by either a major environmental change or a significant time hiatus between Morrison and Cloverly time, or both. Comparison with faunas from the Arundel Formation of Maryland, the Glen Rose Formation (Trinity Group) of Texas and Oklahoma, and the Wealden beds of northwestern Europe indicate at least partial contemporaneity of the Cloverly and Glen Rose Formations and a somewhat greater age for the Arundel and Wealden beds. The age of the Cloverly, on the bases of fossil invertebrate and paleobotanical evidence, as well as the fossil vertebrates, is probably Late Aptian and Early Albian.

ZUSAMMENFASSUNG

Die nichtmarine Schicht des Bighornbeckens, die zwischen der Spät-Jura Sundance Formation und dem Früh-Kreide Thermopolis Schieferton liegt, wurde in drei wesentliche Gruppen unterteilt: Die Morrison, Cloverly und Sykes Mountain Formationen. Die Anwendung dieser Bezeichnungen auf die gegenwärtig zutage tretenden Gesteinsgruppen ist ziemlich unsicher, und es besteht viel Unklarheit und Uneinigkeit über die Formationsbegrenzungen. Traversen entlang des Randes des Bighornbeckens sowie durch angrenzende Gebiete im Norden, Westen und Süden lassen sieben wesentliche Gesteinsschichten erkennen: zuunterst grauer, kalkhaltiger Tonstein; massiger, diamantartig glänzender weisser Quarz-Kieselschiefer Sandstein (quartz-chert) (im südlichen Beckenteil); bunter grau-grün oder rosa kalkhaltiger Tonstein; massiger, schwarzer Kieselschiefer, grober Sandstein oder Konglomerate (im nördlichen Beckenteil) ; grau-weisser oder pastellfarbiger bentonischer, kalkarmer Tonstein, hochhaltig an chalzedonischen und baritischen Konkretionen; unterbrochene Schichten von grobem, gelb-ockerfarbigem tonreichem, feldspathaltigem Flussbettsand; und hellbunter, kalkarmer bentonischer Tonstein, hochhaltig an polierten Geröllen und Kieseln (von einigen Autoren "gastrolithen" genannt). Diese sieben Schichten wurden hier inoffiziell als Stufen I bis VII bezeichnet. Stufen I bis III gehören der Morrison Formation an, Stufen IV bis VII entsprechen ganz oder teilweise den Pryor Konglomeraten, Little Sheep und Himes Schlammsteinverbindungen der Cloverly Formation—so benannt von Moberly (1960). Stufen VI und VII sowie die unteren Sande (Stufe VIII) der darüberliegenden Sykes Mountain Formation entsprechen der Cloverly Formation wie sie Darton 1906 bezeichnete. Einige Autoren verwendeten die Bezeichnung Morrison für die gesamte nichtmarine Schichtenfolge (sequence) und beschränk-

ten die Cloverly Formation auf die Sandbasis (Stufe VIII) von Moberly's Sykes Mountain Formation. Um eine sinnvolle stratigraphische Grundlage zur Klassifizierung von paläontologischen Sammlungen zu erhalten, wurden hier die stratigraphischen Zonen und die Fachsprache von früheren Wissenschaftlern genau verglichen mit den inoffiziell bezeichneten Gesteinsstufen in dieser Studie.

Umfangreiche Sammlungen von versteinerten Wirbeltierüberresten kamen aus den Stufen V, VI und VII. Soweit bis heute bekannt ist, ist diese Fauna bei weitem nicht so vielfältig wie die der Morrison Formation anderer Bezirke. Sie enthält eine neue Art von *Ceratodus* (*C. frazieri*), ein unbestimmbarer Amioid?, zwei baenidische Schildkröten (*Naomichelys speciosa* Hay, 1908 und *Glyptops previcax* Hay, 1908) möglicherweise ein Testudinid, unbezeichnete Mesosuchia Krokodile, und verschiedene Tetrapoden (*Deinonychus antirrhopus* Ostrom, 1969); *Microvenator celer* (eine neue Gattung und Art); eine unbestimmbare Art von *Ornithomimus;* und ein unbestimmbarer aber ausgesprochener grosser Theropod. Ausserdem sind in grosser Menge Überreste von titanosaurischen Sauropoden enthalten, eine neue Gattung und Art von iguanodonischen Ornithopoden (*Tenontosaurus tilletti*) sowie eine neue Gattung und Art von acanthopholischen Ankylosaurier (*Sauropelta edwardsi*). Obwohl alles gründlich gewaschen und gesiebt wurde, wurden keine Säugetier- oder anderen mikrofaunischen Überreste aufgefunden.

Es besteht ein sehr wesentlicher Unterschied zwischen der Cloverly Fauna und der klassischen Morrison Formation. Mit der möglichen Ausnahme von Krokodilüberresten steht kein einziger Cloverlyfund in Beziehung zu einer taxonomischen Einheit der Morrison Formation wie sie bis heute bekannt ist. Andererseits stehen die wenigen fragmentarischen Wirbeltierversteinerungen aus den Stufen I, II und III des untersuchten Gebietes in Beziehung zu den gut geordneten Morrison Einheiten. Weiterhin scheint es, dass alle bis heute bekannten Fundstücke aus der Cloverly Formation (Stufen V, VI und VII) grössere Ähnlichkeiten besitzen mit solchen aus der Spät-Kreide als denen der Morrison Formation. Das ist eventuell zu erklären mit einer Veränderung in der Umgebung oder einer zeitlichen Lücke zwischen Morrison und Cloverly Formationen, oder beidem. Vergleiche mit den Faunen der Arundel Formation von Maryland, der Glen Rose Formation (Trinity Gruppe) von Texas und Oklahoma und den Wealden Schichten Nordwesteuropas zeigen zumindest teilweise eine Gleichzeitigkeit der Cloverly und Glen Rose Formationen und einen grösseren Altersunterschied mit den Arundel und Wealden Schichten. Man schätzt das Alter der Cloverly Formation auf Grund von evertebraten Versteinerungen und paläobotanischen Funden sowohl als auch Wirbeltierversteinerungen als Spät-Aptian und Früh-Albian.

РЕЗЮМЕ

Неморские пласты Бигхорнского бассейна, залегающие между позднеюрской свитой сандане и нижнемеловым термополисовым сланцем, формально подразделены на три наименования: свиты марисок, кловерли и сайкс маунтен. Применение этих названий к действительно выходящим на поверхность пластам было весьма противоречивым, и существует большое разногласие по вопросу о разграничении свит. Наблюдения по периферии Бигхорнского бассейна и в прилегающих районах к северу, западу и югу обосновывают существование семи отличительных пластов: самый нижний, тускло-сероватый, известково-глинистый сланец; массивный, блестяще-белый, кварцево-кремнистый песчаник (в южной части бассейна); пестро-серо-зелёный или розовый, известково-глинистый сланец; массивный, чёрный черт, грубозернистый песчаник или конгломерат в северной части бассейна; тускло-сероватый, переходящий в белый или пастельный, бентонитовый и неизвестково-глинистый сланец с халцедоно-и баритобогатыми конкрециями; прерывистая серия грубозернистых, желтых переходящих в охровый цвет, глинобогатых, полевошпатовых русловых песков, и пестрый, неизвестково-бентонитовый глинистый сланец богатый отшлифованными кремнистыми гальками ("гастролиты" у отдельных авторов). Эти семь пластов обозначены в настоящей работе условными терминами: Пласт I — Пласт VII. Пласты I — III относятся к свите морисон. Пласты IV — VII полностью или частично соответствуют приорскому конгломерату, литл шийпской иловке и хаймским иловковым пачкам свиты кловерли, как определил эту свиту Моберли (1960). Пласты VI и VII и нижние пески (Пласт VIII) вышележащей свиты сайкс маунтен, соответствуют свите кловерли, как ее определил Дартон в 1906 г. Отдельные авторы обозначили названием морисон всю неморскую толщу и ограничили свиту кловерли базальными песками (Пласт VIII) свиты сайкс маунтен Моберли. Для того, чтобы предложить адекватную стратиграфическую основу для размещения полученных палеонтологических коллекций, стратиграфические единицы и терминология предыдущих исследователей подробно сравниваются с принятыми в этой работе условными пластами.

Обширные коллекции ископаемых остатков позвоночных были составлены из Пластов V, VI и VII. Эта фауна гораздо менее разнообразна, чем фауна свиты морисон в других районах. К ней относятся новый вид *Ceratodus (C. Frazieri)*, неопределенный амиоид, две баенаидовые черепахи *(Naomichelys speciosa Hay,* 1908 и *Glyptops pervicax* Hay, 1908), возможный тестудинид, неопределённые мезозуховые крокодиловые, и несколько тероподов *(Deinonychus antirrhopus* Ostrom, 1969); *Microvenator celer* [новый род и вид]; неопределенный вид *Ornithomimus*; неопределенный, но отличительный, крупный теропод. Также в наибольшем количестве имеются остатки одного титанозаврида (ящероногих), нового рода и вида игуанодонтида (птиценогих) *(Tenontosaurus tilletti)*, нового рода и вида акантофолидового анкилозавра *(Sauropelta edwardsi)*. Несмотря на обширное промывание и просеивание не удалось обнаружить никаких остатков, ни млекопитающих, ни другой микрофауны.

Фауна кловерли во всех отношениях отличается от фауны классической свиты морисон. За возможным исключением крокодиловых остатков нет ни одного образца кловерли, который не относится к таксону известному от свиты морисон. С другой стороны, те немногочисленные фрагментарные ископаемые остатки позвоночных, обнаруженные в Пластах I, II и III в исследуемом районе относятся к хорошо известным таксонам морисона. Кроме того, все до сих пор известные образцы из свиты кловерли (Пласты V, VI и VII), повидимому, имеют более близкие сходства с верхнемеловыми таксонами, чем с видами морисон. Это обусловливается или крупным изменением во внешней среде или значитель-

ным временным пробелом между морисоном и кловерли (или обеими причинами). Сравнение с фауной свиты арундел Мэриленда, свиты Глен Роз (группа Троица) Техаса и Оклахомы, уэлденских пластов северозападной Европы свидетельствует по крайней мере о частичной одновременности свит кловерли и Глен Роз, о сравнительно старшем возрасте пластов арундел и уэлден. Возраст кловерли, на основании ископаемых безпозвоночных и палеоботанических данных, как и ископаемых позвоночных, повидимому, приурочивается к позднему апту и раннему альбу.

1. INTRODUCTION

The Mesozoic section in much of the western interior of the United States is characterized by a prominent sequence of nonmarine, variegated claystones and sandstones measuring up to 700 feet (200+ m) in thickness that is generally considered to be of Late Jurassic and Early Cretaceous age. The lower part of this sequence, widely referred to as the Morrison Formation, has produced perhaps the most significant and diverse terrestrial vertebrate fauna known from all of the Mesozoic. The upper part of the sequence is variously referred to as the Cloverly, Kootenai, Dakota, Inyan Kara, Lakota-Fuson, Gannett, Lytle, Cedar Mountain or Burro Canyon Formation, but until now it has contributed less than half a dozen fragmentary fossil vertebrate specimens to our published knowledge. After years of debate, the age of the Morrison Formation is now generally accepted as Kimmeridgian to Early Portlandian (Simpson, 1926; Baker, Dane and Reeside, 1936); the overlying nonmarine strata are considered as Aptian or Early Albian (Peck, 1941, 1951; Peck and Craig, 1962; Stokes, 1952).

The apparent absence of fossil vertebrates in strata overlying the Morrison Formation, together with the fact that Early Cretaceous vertebrates are exceedingly rare and poorly known from all regions of North America, prompted the present investigation. Added to these were the efforts of several individuals, particularly during the 1930's and 1940's, that resulted in intriguing collections purportedly from the Cloverly Formation of Montana. None of this early work has been reported, but the nature of the materials indicates that a fauna quite distinct from that of the Morrison Formation apparently does exist in the upper part of this nonmarine sequence. In spite of inadequate stratigraphic data, it appeared that these collections might well represent the most significant evidence available of Early Cretaceous vertebrates in the Western Hemisphere.

Aside from these earlier unreported collections from the "Cloverly", the sum total of our knowledge of Early Cretaceous terrestrial vertebrates in North America rests on very fragmentary or isolated materials from: 1) the Arundel Formation of Maryland (Marsh, 1888; Lull, 1911a, 1911b; Gilmore, 1921), 2) the Trinity Group of Texas and Oklahoma (Larkin, 1910; Stovall and Langston, 1950; Patterson, 1951, 1955, 1956; Slaughter, 1965), 3) the "Lakota" of South Dakota (Lucas, 1901, 1902; Gilmore, 1909), 4) the Kootenai of Montana (Olson, 1960), and 5) the Dakota of Kansas (Eaton, 1960). In addition, a solitary specimen, often cited as Late Cretaceous in age but almost certainly from the Dakota sandstone capping Como Bluff in southern Wyoming, the type of *Nodosaurus textilis,* was described by Marsh (1889). These constitute the published record of Early Cretaceous vertebrate life in North America.

Although the Late Jurassic-Early Cretaceous continental sequence is widespread throughout most of the western interior (exposures of part or all of this sequence occur locally in New Mexico, Arizona, Texas, Oklahoma, Colorado, Utah, Wyoming, Montana, Idaho, South Dakota and Kansas), the present study was restricted to a relatively small area in north-central Wyoming and south-central Montana (Fig. 1). Reconnaissance of several possible areas by the writer during the summers of 1957 and 1958 indicated that the periphery of the Bighorn Basin and adjacent regions offered the most extensive exposures of the critical upper part of the section. Another decisive factor was the unreported collections mentioned above of Barnum Brown, Roland T. Bird, A. Silberling and J. W. Stovall from this and nearby areas in Montana. The area selected comprises parts of Hot Springs, Washakie, Big Horn and Park Counties in Wyoming and Carbon, Big Horn and Yellowstone Counties in Montana. The precise area is shown in Figure 2 (in pocket). Within this area the upper part of the continental sequence is referred to as the Cloverly Formation (Darton, 1904, 1906), although in the northern sectors it is sometimes termed the Kootenai.

Limited investigations were also carried out in parts of Fremont and Teton Counties, Wyoming, and Wheatland County, Montana; some of the results are included in this report. Stratigraphic comparisons, but no collecting, were also extended to Weston, Albany, Johnson, Natrona, Carbon and Sheridan Counties in Wyoming and to Judith Basin and Fergus Counties in Montana.

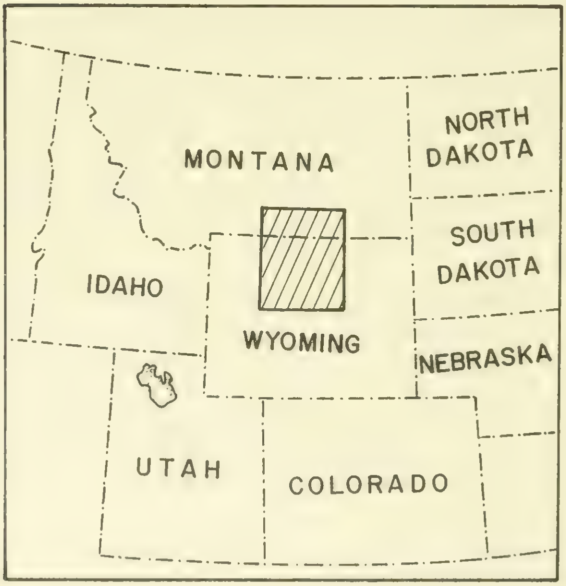

FIG. 1. Index map showing the location of the area including in this study.

ACKNOWLEDGEMENTS

The cooperation and assistance of a great many individuals contributed immeasurably to the successful completion of this study. It is not possible to mention each contributor by name—the list is much too long—but I am indebted to everyone who aided us in this project.

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Field exploration and collecting cannot be carried out without the cooperation and consent of local residents and landowners. I am grateful to the scores of individuals in the Bighorn Basin and Crow Indian Reservation who greatly facilitated our work and who on more than one occasion extended a generous and most welcomed helping hand to save us from gumbo, broken axles and camp cooks. I especially wish to acknowledge the assistance and hospitality of Dr. Harold McCracken, Director of the Whitney Gallery of Western Art in Cody, Wyoming; the Tillett family of Lovell, Wyoming—Lloyd, Royce, Ab, Marion and Bess; the Wilford Frazier family of Billings, Montana; Thor Lande, Tom and Nell Edwards, Paul Petersen, Richard Leavitt and Lee Hoffmann. On behalf of all the crew I extend sincere thanks.

A major part of the area investigated lies within the Crow Indian Reservation in southern Montana. Exploration of these areas was facilitated by the Crow Tribal Council and officials of the Bureau of Indian Affairs: Superintendent Otto Weaver, Director of Area Affairs Ned O. Thompson, Realty Officers Robert Seitz, R. S. McDermott and Geneva Miller. Reconnaissance of limited areas in the Wind River Reservation of Wyoming was approved by the Arapahoe-Shoshone Joint Tribal Council, Superintendent Clyde Hobbs, and Realty Officers Robert Schoewe and Geneva Miller.

Field assistants during the five field seasons (1962–1966) were: Ray Breuninger, Thomas Churchill, Jon Hall, Larry Spencer, Gary Wright, Stephen Burrell, Harold Brown, Robert Bakker, Marc Hecht, Peter Parks, Roger Rice, Frederic Mulhauser, Roseanne Leidy Pilbeam, Ralph Molnar, Donald McGuire, Scott Frazier, John Thomson, John Russell, John Marr, Farish and Eleanor Jenkins and Grenville Thoron. These students were ably supervised by Roy Winslow, Thomas Walsh, Grant Meyer, Peter Parks, Ronald Brown and Clyde Weinman of the Peabody Museum staff. I am grateful to each for a job well done.

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The illustrations were prepared by Ward Whittington and Roseanne Rowan, the maps and charts by Mary Ann Clow, Judy Chaney and Daphne Zachary. Rebekah Smith ably assisted in the preparation of charts and maps and in data compilation. Photographs in Plates 1–21 are by John Howard, A. H. Coleman, Thomas Brown and the author. Photographs of Plates 22–27 are by Elwood Logan of the Division of Photography, The American Museum of Natural History.

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Abbreviations: Institutional names have been abbreviated as follows throughout this report:

AMNH — American Museum of Natural History, New York City, New York
BB — Buffalo Bill Museum, Cody, Wyoming
BM(NH) — British Museum (Natural History), London
CM — Carnegie Museum, Pittsburgh, Pennsylvania
FMNH — Field Museum of Natural History, Chicago, Illinois
IRSNB — Institut Royal des Sciences Naturelles de Belgique, Brussels
NMC — National Museum of Canada, Ottawa, Ontario
OU — J. Willis Stovall Museum of Science and History, University of Oklahoma, Norman, Oklahoma
PU — Princeton University Museum, Princeton, New Jersey
ROM — Royal Ontario Museum, Toronto, Ontario
SM — Sedgewick Museum, Cambridge University, Cambridge
UKM — University of Kansas Museum, Lawrence, Kansas
USNM — United States National Museum, Washington, D.C.
YPM — Peabody Museum of Natural History, Yale University, New Haven, Connecticut

2. STRATIGRAPHY

Several factors require that a detailed analysis of the stratigraphy, including a review of previous investigations, be presented before consideration is given to the systematic paleontology. First and most important of these is the necessity of providing a framework in which to record the precise stratigraphic occurrence of all fossil collections. Second, because of the many conflicting interpretations and diverse definitions by past workers (Fig. 3), there is considerable confusion as to exactly what has been, or may be, intended by past and current use of the terms "Cloverly, Morrison, Greybull, Pryor, rusty beds", etc. Consequently it is essential that stratigraphic terminology as used in this report be clearly defined and compared as precisely as possible with the usage of previous workers. To accomplish this, it was necessary to visit the sites of all previously published measured sections. Charts 1 to 7 compare these earlier interpretations of specific sections with the terminology of this report.

The sole purpose of the lengthy stratigraphic discussion which follows is to eliminate diverse or inconsistent applications of terminology as a source of confusion, so that the collections reported here can be placed in any or all stratigraphic contexts (Darton's, Lee's, Fisher's, Hewett's or Moberly's, etc.). It is not important to me at this point which usage the reader prefers. What is important is that stratigraphic data relating to our collections be accurately and unmistakably translatable into terms that have been used by others. Darton's Cloverly Formation exists as a formal term, at least, and has been applied by numerous geologists to rock strata within the western interior. It has not yet been demonstrated, however, whether or not his *specific lithic units* can be recognized with certainty outside the immediate vicinity of his type area. Most geologists after Hewett and Ziegler believed that they could distinguish between Darton's Cloverly and the Morrison Formation; a few, however, have declined to select a boundary. Whether or not this nonmarine sequence should be subdivided into two formations is not of primary concern in this report (although it is my own opinion that such twofold division is both useful and warranted on stratigraphic grounds). The primary concern is whether Darton's Cloverly Formation can be recognized with certainty throughout the Bighorn Basin and adjacent regions. My conclusion is that it can.

In the discussions that follow it will be evident that identification and correlation of specific lithic units within the Morrison-Cloverly sequence are often extremely difficult. Persistent key horizons are rare or difficult to recognize in widely separated exposures. Few lithic units seem traceable over great distances with any degree of confidence. Correlations between spot localities are questionable, to say the least, due to pronounced lateral and vertical facies changes, wedging and erosional gaps in the section. The only practical method upon which to establish correlations is by walking out exposures, but, in spite of an abundance of exposures in the study area, outcrops are discontinuous and in some places separated by several miles or more. Fortunately (or unfortunately), the only means of discovering fossil vertebrate remains is by walking out exposures, and in the course of our search the entire outcrop belt of the Morrison-Cloverly sequence encircling the Bighorn Basin (Fig. 2, in pocket) was traversed. The generalized stratigraphic section that follows is based on observations and data collected on this traverse. Documentation is presented at the back of this report in

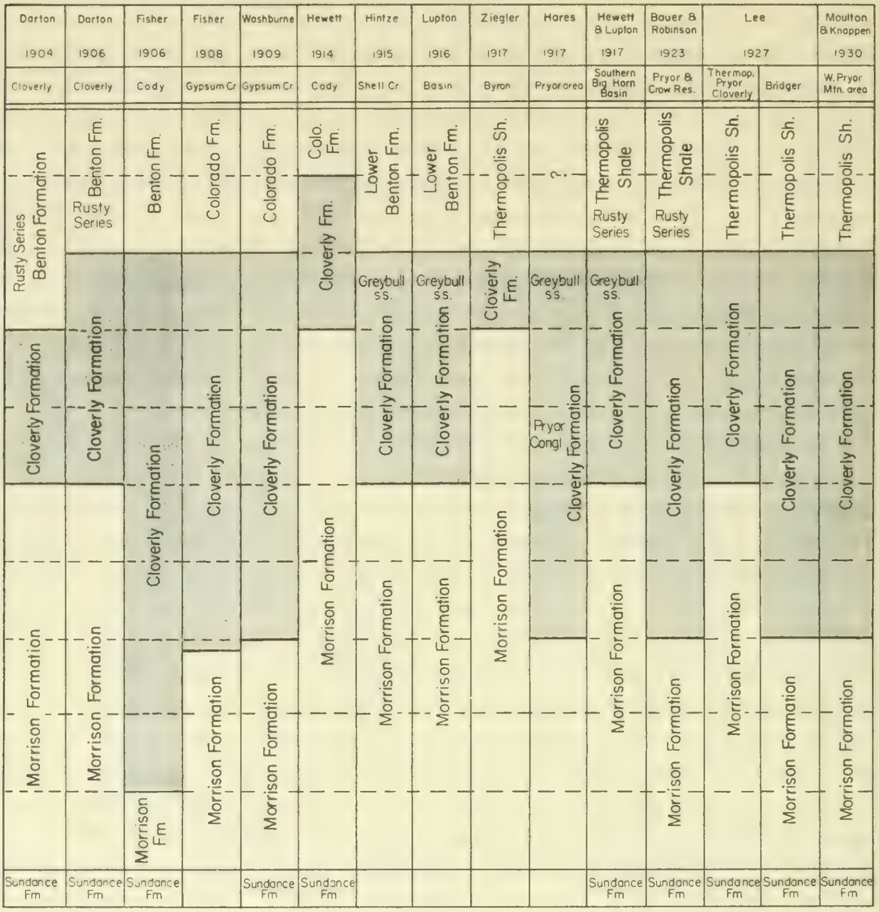
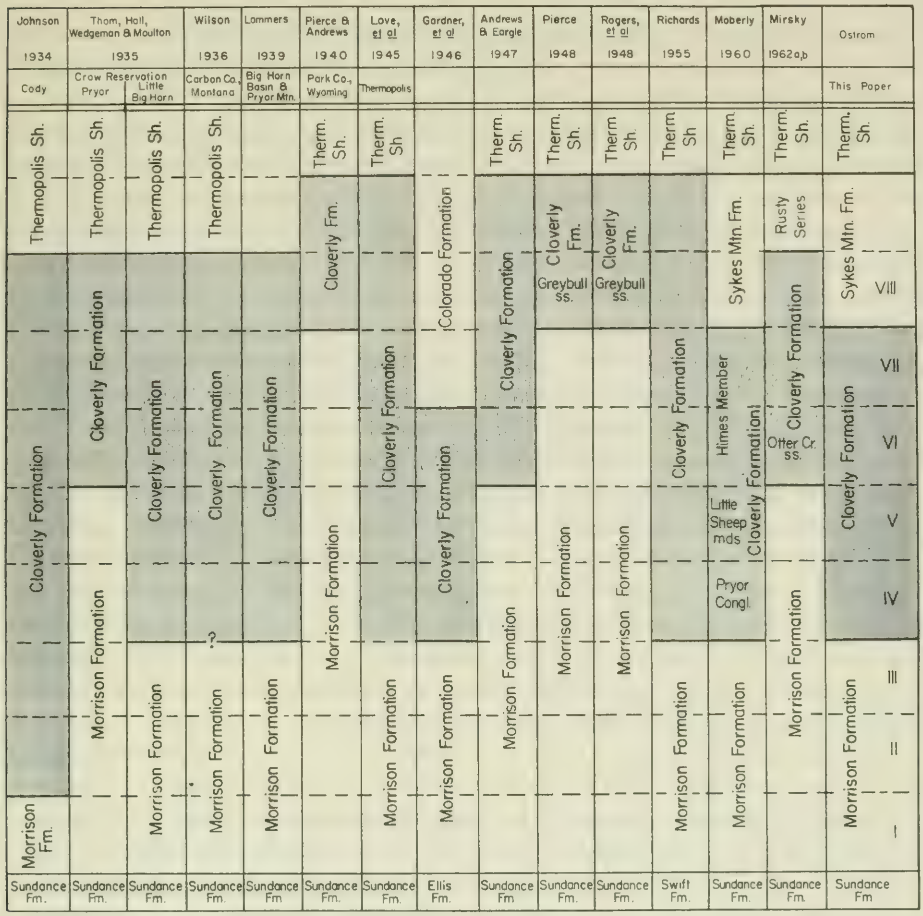

Darton 1904 Cloverly
Darton 1906 Cloverly
Fisher 1906 Cody
Fisher 1908 Gypsum Cr
Washburne 1909 Gypsum Cr
Hewett 1914 Cody
Hintze 1915 Shell Cr
Lupton 1916 Basin
Ziegler 1917 Byron
Hares 1917 Pryor area
Hewett & Lupton 1917 Southern Big Horn Basin
Bauer & Robinson 1923 Pryor & Crow Res.
Lee 1927 Thermop. Pryor Cloverly
Bridger
Moulton & Knappen 1930 W. Pryor Mtn. area
Rusty Series Benton Formation
Benton Fm.
Rusty Series
Colorado Fm.
Colo. Fm.
Lower Benton Fm.
Thermopolis Sh.
?
Thermopolis Shale
Greybull ss.
Cloverly Fm.
Cloverly Formation
Pryor Congl
Morrison Formation
Morrison Fm
Sundance Fm

FIG. 3. Comparison of Upper Jurassic – Lower Cretaceous nonmarine

the 28 measured sections of Appendix A (see also Fig. 4, in pocket) and in several photographs at critical localities (Plates 1 to 7).

The Mesozoic sequence is extensively exposed in the study area along the eastern, southern and northwestern margins of the Bighorn Basin and around the western and northern flanks of the Pryor Mountains. Outcrops occur in low cuestas, prominent hogbacks and extensive badlands bordering the Bighorn, Owl Creek, Pryor and Absaroka–Beartooth Mountain uplifts and in numerous subsidiary anticlinal structures. Near the middle of this section is a sequence of 200 to 600 feet (60 to 180 m) of variegated, often brightly colored, claystones, fine-grained to conglomeratic sandstones, shales and channel sands of continental origin. These beds are usually mapped as a single unit "Morrison-Cloverly undivided", although most discussions treat the two formations separately. Of the two, only the Cloverly Formation is based on local studies and can be referred to a local type section. The term "Morrison" has been ex-


Johnson 1934 Cody
Thermopolis Sh.
Cloverly Formation
Morrison Fm.
Sundance Fm.
Thom, Hall, Wedgeman & Moulton 1935 Crow Reservation Pryor Little Big Horn
Thermopolis Sh.
Cloverly Formation
Morrison Formation
Sundance Fm.
Wilson 1936 Carbon Co., Montana
Thermopolis Sh.
Cloverly Formation
?
Morrison Formation
Sundance Fm.
Lammers 1939 Big Horn Basin & Pryor Mtn.
Cloverly Formation
Morrison Formation
Sundance Fm
Pierce & Andrews 1940 Park Co., Wyoming
Therm. Sh.
Cloverly Fm.
Morrison Formation
Sundance Fm.
Love, et al 1945 Thermopolis
Therm. Sh
Cloverly Formation
Morrison Formation
Sundance Fm.
Gardner, et al 1946
Colorado Formation
Cloverly Formation
Morrison Formation
Ellis Fm.
Andrews & Eargle 1947
Therm. Sh.
Cloverly Formation
Morrison Formation
Sundance Fm
Pierce 1948
Therm. Sh.
Cloverly Fm.
Greybull ss.
Morrison Formation
Sundance Fm.
Rogers, et al 1948
Therm Sh.
Cloverly Fm.
Greybull ss.
Morrison Formation
Sundance Fm.
Richards 1955
Therm Sh
Cloverly Formation
Morrison Formation
Swift Fm.
Moberly 1960
Therm. Sh.
Sykes Mtn. Fm.
Himes Member
Little Sheep mds
Pryor Congl.
Cloverly Formation
Morrison Formation
Sundance Fm.
Mirsky 1962a,b
Therm. Sh.
Rusty Series
Cloverly Formation
Otter Cr. ss.
Morrison Formation
Sundance Fm.
Ostrom This Paper
Therm. Sh.
Sykes Mtn. Fm.
VIII
VII
VI
V
IV
Cloverly Formation
III
II
I
Morrison Formation
Sundance Fm

stratigraphic terminology as used by previous workers in the Bighorn Basin area.

tended to this area through common practice from the classic Morrison exposures in Colorado, chiefly on the basis of nearly continuous surface exposures and of well logs that show Morrison type lithologies are present in the subsurface. Only Mook (1916) has published regional studies comparing the Morrison facies between Colorado and northern Wyoming.

In the study area, the nonmarine sequence lies with apparent conformity on glauconitic, calcareous sandstones and shales commonly rich—even coquinoid—in marine invertebrate remains. In this study the base of the nonmarine sequence was placed at the highest occurrence of marine invertebrate fossils because of the highly variable lithologies immediately above that level. The Morrison-Cloverly sequence is overlain conformably by some 300 to 600 feet (90 to 180 m) of fissile, black, bentonitic, marine shale. The underlying unit is referred to as the Upper Sundance Formation; the overlying unit as the Thermopolis Shale.

GENERALIZED STRATIGRAPHIC SECTION

It is almost superfluous to note that the Morrison-Cloverly sequence varies considerably from one place to another, but this is by far its most prominent feature. Variation consists of changes in rock type and color, topographic expression and differences in sequence and thickness. Yet within this variable sequence is a broad pattern that is quite persistent—at least within the study area. The lower half of the section is normally calcareous, regardless of lithology. Claystones are calcareous and locally contain calcareous nodules or thin freshwater limestone strata. Sandstones usually feature calcareous cement. On the other hand, the upper half of the section is rarely calcareous. Instead it is rich in authigenic silica and bentonite. Moberly (1960) noted this distinction, but otherwise it apparently has been overlooked in the Bighorn Basin.

The nonmarine sequence can be divided into eight recognizable major units within the study area. Although one or more may be absent at a given locality, several are remarkably persistent throughout the region and most can be recognized in particular outcrops. Some of these have been noted by other workers and a few have been formalized as formations or members. These eight subunits are persistent enough and sufficiently distinct to serve as useful reference units for placement of the paleontologic materials and for consideration of stratigraphic interpretations. In order to avoid the multiple meanings that are associated with the classical terms now in use, numerical designations are applied to these units in this report.

The lower, calcareous part of the Morrison-Cloverly sequence has been subdivided here into three units (labeled Units I, II, and III) based chiefly on exposures in Hot Springs, Big Horn (Wyoming) and Carbon (Montana) Counties. Units I and III are massive or poorly stratified, drab-yellow to gray-green, silty claystones. They are very similar to each other, so similar in fact they cannot be distinguished in limited exposures or in the absence of Unit II. Unit II consists of 20 to 75 feet (6 to 23 m) of brilliant white to buff or yellow-green quartz sandstone, usually massive, cross-laminated, poorly jointed and calcareous with chalky-white chert grains.

The upper, noncalcareous part of this sequence is subdivided here into four elements (Units IV, V, VI and VII). Of these, the uppermost is by far the most persistent and prominent—in fact, it is the only part of the entire nonmarine sequence that apparently is not absent anywhere within the study area. These four units consist of a lower conglomerate or conglomeratic sandstone (Pryor Conglomerate of some authors), a lower claystone (Unit V), an upper, discontinuous, channel sandstone which occasionally is conglomeratic (Unit VI) and an upper claystone (Unit VII). In contrast to the claystones of the lower half of the sequence, Units V and VII are readily distinguished even in the absence of any of the other units. As will be shown, Unit V is everywhere characterized by frequent to abundant chalcedony and barite concretions, whereas these are absent in Unit VII and apparently in nearly all exposures of the lower claystones. Unit VII on the other hand contains rare to abundant, highly polished and rounded "gastrolith"-like pebbles.

While it may be argued that the occurence of chalcedony, like any other single character, should not be considered an absolute or distinctive feature upon which to identify a particular stratigraphic unit, after traversing nearly all of the relevant exposures, I am satisified that this character can be so used in this region. The most significant evidence for this conclusion is the apparently constant stratigraphic position of chalcedony-concretion-bearing claystone within the Morrison-Cloverly sequence. The Pryor Conglomerate (or an identical, black chert pebble conglomerate), when present, always lies immediately beneath this claystone. And a brightly colored, non-chalcedony-bearing claystone always overlies it, frequently with a coarse, poorly sorted, feldspathic sandstone (Unit VI) lying between them.

The origin of these chalcedony (and barite or calcite) concretions is not known. Chert concretions usually are characteristic of carbonate rocks and are thought by some to have resulted from selective replacement of calcareous matrix by amorphous silica. Chert concretions are much less common in detrital rocks, but when present appear to be secondary structures resulting from local concentration of silica during diagenesis. Detrital materials and primary bedding structures are preserved within such nodular bodies. The present examples, however, show no primary sedimentary structures, contain few or no recognizable detrital grains, and consist entirely of amorphous chalcedonic chert, barite, or (in lesser amounts) calcite. They occur as widely scattered, isolated features, or are concentrated in restricted zones or local concentrations. A detrital origin seems improbable for there are no signs of abrasion and they are never associated with pebbles, cobbles or other coarse detrital fragments. The evidence seems to indicate a primary origin, presumably as a hydrous silica gel accumulated in irregular masses at various times during accumulation of volcanic ash and the detrital clay. Whatever the origin, the chalcedony-barite concretions are by far the most useful criterion for field recognition of the upper subdivisions of the Morrison-Cloverly sequence.

As noted previously, Unit VII differs from Unit V in the abundant occurrence of scattered, well-rounded and highly polished chert or quartzite pebbles, held by some to be dinosaur stomach stones or "gastroliths", and the complete absence of chalcedony-barite concretions. In addition, Unit VII is generally much more brightly colored and is rarely bentonitic. The so-called gastroliths range from less than 1 inch (2.5 cm) to more than 6 inches (30 cm) in maximum dimension, but usually fall within the 1 to 2 inch (2.5 to 5 cm) range. Sample collections consisted of less than 3 percent nonsiliceous material. The source of these objects is not known, but no evidence was found during the course of this investigation to support the popular, but improbable, thesis that they represent dinosaur gizzard stones. Although often encountered during quarry operations, not a single "gastrolith" was found closely associated with any of the numerous articulated skeletons collected by Yale expeditions. Dorr (1966) has presented evidence suggesting that such polished pebbles are wind-polished, but the general absence of even poorly defined facets on most pebbles from Cloverly exposure suggests other factors. Conclusive evidence has not yet been found, but the most plausible explanation to date attributes such highly polished pebbles to normal sedimentary processes (Stokes, 1942).

Unit I. The lowermost unit consists of calcareous claystones[1] and siltstones, usually greenish in color with prominent red-brown banding locally and containing occasional or frequent, usually thin, discontinuous, calcareous sandstone lenses. It rests conformably, and at some places gradationally, on glauconitic sandstone, gray-green shale or limestone containing marine invertebrates. Thick, massive, nonresistant claystone or poorly stratified shale predominate, but locally resistant sandstones 1 to 10 feet (0.3 to 3.0 m) thick and thin limestone strata occur. Sandstone lenses are rarely clean, usually contain abundant clay matrix, and are marked by cross-laminations and occasional ripple-marked surfaces. Moberly (1960: p. 1168) reported the dominant clay mineral to be illite. Unit I varies from 70 to 170 feet (21 to 51 m) in thickness and corresponds to the lower part of the Morrison Formation of most workers.

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[1] The term claystone is applied to fine-grained sedimentary rock in which clay-sized grains predominate, there is no bedding structure or it is obscure, and the rock is nonfissile, having blocky or conchoidal break in fresh samples. The term shale is applied to similar fine-grained sedimentary rock that possesses conspicuous parallel stratification and is fissile.

Unit II. Overlying Unit I on a surface of some relief is a prominent, massive, white sandstone ranging from 10 feet (3 m) to more than 80 feet (24 m) in thickness, but normally about 45 feet (14 m) thick. It varies from medium- to coarse-grained, locally with pebbles up to 10 mm in diameter. The coarse fraction consists predominantly of well-rounded grains of quartz and white chert, the latter making up 15 to 20 percent. The cement is calcite; the clay matrix is negligible except in the lower 1 to 3 feet (0.3 to 0.9 m). It weathers to pale greenish yellow, light tan or brilliant white, forms smooth, steep slopes or large, rounded knobs. Jointing is rare and vertical exposures accordingly are infrequent. Unit II generally is exposed in massive 10 to 20 foot (3.0 to 6.0 m), cross-laminated beds, but thinly bedded strata are present locally, especially near the top. It is a prominent ledge-former in the western and southern parts of the study area but has not been recognized with assurance in the northern areas. Unit II falls within the lower part of the Morrison Formation as it is defined by most students of this region.

Unit III. This unit consists of 30 to 120 feet (9.0 to 36 m) of nonresistant, variegated claystone that weathers to greenish gray, pale yellow, light gray and pink. In general it resembles Unit I and in the absence of Unit II cannot be readily distinguished from that unit. Locally, red-brown bands occur, but these are not as vivid or as common as those in Unit I. Fresh rock is dark to medium gray and gray green and breaks into irregular small chips. It is universally calcareous and silty. Thin, discontinuous calcareous sandstone strata are common and white limestone beds up to 1 foot (0.3 m) thick occur locally. At some localities, white to dark-gray calcareous concretions are abundant. The dominant clay mineral is illite, according to Moberly (1960: p. 1168). The unit commonly weathers to low-angle slopes except where it is protected by an overlying resistant sandstone or conglomerate. Unit III corresponds to the upper part of the Morrison Formation as it has been redefined by Moberly (1960) and to the middle part of that formation as it has been interpreted by others.

Unit IV. Overlying Unit III, particularly in outcrops along the west flank of the Bighorn Mountains north of Shell Creek and along the west and northwest flanks of the Pryor Mountains, is a thick, massive and very resistant conglomeratic sandstone and conglomerate, which has been formally recognized as the Pryor Conglomerate. Here it is designated Unit IV. Exposures are particularly well developed in the vicinity of Sykes Mountain, Crooked Creek, Red Dome and Bluewater Creek, but the same facies is present at about the same level near the type Cloverly section and northeast of Thermopolis. The unit varies from about 10 feet (3.0 m) to more than 50 feet (15.0 m) thick, generally weathers to a dark gray or gray brown and consists of coarse sand, pebbly sand and conglomeratic lenses. Pebbles and sand grains consist chiefly of black, dark gray, or brown chert. Some light-gray quartzite and white quartz is present in northern exposures. Feldspar grains constitute less than 2 or 3 percent of the sand fraction. Clay matrix is generally lacking or only a minor component, but when present consists of kaolinite (Moberly, 1960: p. 1168). Pebble fraction varies greatly both laterally and vertically, pebbles generally being concentrated in 2 to 10 inch (5.0 to 25 cm) zones or in restricted (4 to 8 foot long [1.2 to 2.4 m]) wedges or cross-beds. Pebbles range from pea size to 2 inches (5.0 cm) in diameter. In the Pryor Mountain area, Unit IV caps many of the ridges and cuestas. The basal contact is sharp and may be unconformable regionally. C. J. Hares (1917) is credited with coining the term Pryor Conglomerate and was one of the first to adopt this unit as the basal member of the Cloverly Formation. Several subsequent studies have followed this usage (apparently equating it with the "conglomerate sandstone" described by Darton at the base of the Cloverly), but others place the Morrison-Cloverly contact well above this unit.

Unit V. Unit IV is overlain by a rather persistent, predominantly unstratified, noncalcareous claystone, which varies from drab neutral, light to medium gray to pastel and sometimes rather brightly variegated colors. It is the variable nature of weathered coloration of this unit that apparently has caused much of the difficulty in subdividing the section. Where drab in color it resembles the claystones of Unit III; where brightly variegated it resembles overlying claystone that is here labeled Unit VII. In the absence of intervening coarse clastic facies, no precise division can be made between Unit V and Unit VII. The claystone is typically medium to dark gray, sometimes greenish or with a purple tinge on fresh exposures. It is highly bentonitic, particularly in the upper part, and usually is rich in chalcedony, calcitic and barite concretions. Concretions occur either in distinct zones, or scattered throughout the entire thickness, and vary in abundance from rare to extremely abundant. Concretions usually are about fist size and range from white, milky gray, blue, lilac to yellow. Some are nearly opaline in appearance. In composition, they vary both locally and stratigraphically from pure chalcedony, quartz and chalcedony with minor amounts of calcite and/or barite, to nearly pure calcite or barite. The entire sequence varies from 20 (6.1 m) to nearly 200 feet (61 m) in thickness and features occasional, fine-grained, quartz sandstone lenses and thin, finely crystalline, white limestone layers, both ranging up to 18 inches or 2 feet (0.45 to 0.61) m) in thickness. Occasional channel sands up to 30 feet (9 m) across and 6 to 12 feet (1.8 to 3.6 m) thick also occur. At some localities selenite crystals and white, pink or orange satin spar veins are common.

Along the eastern perimeter of the Bighorn Basin, specifically in the Shell Creek, Cloverly and Sheep Mountain areas, a thin, highly weathered, fragmental tuff occurs in the upper part of Unit V. Ranging from less than 6 inches (15 cm) to more than 28 inches (70 cm) in thickness this tuff is prominently exposed as a brilliant white band in the upper third of Unit V. No sign of this unit was recognized in the northern, western or southern margins of the basin. Plates 1: A and B, 2: A and 3: A and B show this volcanic unit as a conspicuous white band near the top of Unit V. Unfortunately, this tuff is so highly altered that radiometric dates could not be obtained.

Unit V typically weathers into low, rounded, pale-purple, gray or nearly white, sometimes pinkish-gray, vegetation-free, gumbo hills with very soft, "popcorn" surfaces strewn with chalcedony concretion fragments. At some localities the section is rather vividly colored, but at most exposures the colors are pastel or drab neutral colors. Fresh rock is generally dark gray with little or no mottling; it breaks into irregular, waxy-lustered chips. Unit V corresponds to the upper part of the Morrison Formation of some authors and the lower or middle parts of the Cloverly Formation of others. It represents the middle portion of the Morrison Formation of at least two interpretations. Moberly (1960: p. 1145) has proposed this unit as the Little Sheep Mudstone Member of his redefined Cloverly Formation.

Unit VI. Unit VI is a coarse-grained, discontinuous channel deposit that is almost always present at the top of the chalcedony-concretion-rich claystone (Unit V). The unit consists of 2 to 75 feet (0.6 to 25 m) of olive, yellow or brown, sometimes tan, "salt and pepper" sandstone. Locally it is pebbly, but rarely would it be considered a conglomerate. Sand grains are subangular to angular and consist largely of feldspar, quartz and some dark minerals. Coarse fragments are gray or yellow chert and light-colored quartzite in northern exposures, but chiefly white chert in southern outcrops. Unit VI is typically impure with considerable clay matrix that Moberly (1960: p. 1168) reports as predominantly montmorillonite. Locally, this sandstone may be well indurated, forming a massive, resistant ledge, but usually it is rather friable, disintegrates readily, and is often concealed or poorly exposed at the base of steep cliffs or slopes formed by the overlying claystones. Parallel stratification is usually obscure; cross-laminations are common. The basal contact is sharp and irregular with relief up to 5 or 6 feet (1.5 to 1.8 m) over a 100 foot (30 m) distance. Clay pebbles and angular fragments are common in the lower 2 to 6 inches (5 to 15 cm). The contact with the overlying claystone is usually gradational. Although the unit is discontinuous and clearly represents multiple channel sands, informal stratigraphic designation is justifiable because of the nearly universal occurrence of this facies at what appears to be a constant stratigraphic level. Unit VI corresponds to the basal sandstone of the Cloverly Formation as described by Darton (1906), but other students have included it in the middle or upper part of the Morrison while Moberly considers it part of his upper (Himes) member of the Cloverly.

Unit VII. The most persistent, and one of the most prominent facies of the entire nonmarine sequence is the 20 to 100 feet (6 to 30 m) of brightly colored, variegated claystone that everywhere overlies Unit VI. These claystones are gradational with the underlying sands at most localities. Usually they weather into steep, "fluted" slopes or cliffs and occasional badlands with maroon, red, orange, deep-purple and red-brown colors predominating. Neutral grays and pastel shades occur rarely and locally. Chalcedony concretions are lacking, satin spar occurs rarely, but highly polished pebbles commonly referred to as "gastroliths" are almost always present throughout the region and at some localities are extremely abundant. The pebbles often are concentrated at the base of the claystone cliffs or on the gentle slopes below, where they are associated with concentrations of chalcedony concretions, but they are derived from the steeper outcrops of Unit VII. (A random collection of these "gastroliths" consisted of 97 percent silica—quartz, quartzite, chert, chalcedony.) Fresh rock is generally light gray green to yellow and pale purple with dark gray-green and red-brown mottling. It breaks into large, irregular blocks with conchoidal fracture and abundant slickensides. Bedding is obscure or absent, except in the highest portions where it sometimes grades into thin-bedded sandstones or fissile shale. The unit is often sandy, rarely calcareous and only locally bentonitic. Sandstone strata and wedges from 2 to 6 feet (0.6 to 1.8 m) thick are common, consisting of quartz with some feldspar usually in well-rounded grains. Unit VII represents the middle member of Darton's Cloverly but has been interpreted as both the upper member of that formation and of the Morrison Formation.

Unit VIII. Capping the vividly colored claystone of Unit VII is a persistent, but variable, sequence of up to 30 feet (9 m) of massive and/or thinly bedded sandstones and siltstones interbedded with gray to black, fissile shales. The entire sequence weathers to a yellow or rust-brown color and is often rich in ironstone concretions, black hematite laminae and abundant hematite and limonite staining. Where massive sandstones occur, it stands up as a resistant cap rock. The sandstones consist of fine- to medium-grained, well-rounded quartz grains. Ripple marks and fucoidal impressions are abundant, locally occurring on virtually all bedding planes. True cross-beds are rare. Precise thicknesses are difficult to obtain because of the highly gradational nature of the contact with the overlying, black, bentonitic shale of the Thermopolis Formation. No recognizable, persistent contact or horizon was found on which to separate one from the other. Unit VIII corresponds to the lowest part of the "rusty beds" of many authors. Moberly (1960) has proposed formalization of the "rusty beds" as the Sykes Mountain Formation based on exposures near the Montana-Wyoming state line north of Lovell. Where a massive sandstone is present, Unit VIII equals the Greybull sandstone of some authors.

A major point I wish to make with regard to this generalized stratigraphic section is that it is possible to distinguish the two upper claystone sequences from each other and in most instances from either of the two lower claystones, regardless of whether or not intervening coarse clastic units are present. This separation is possible on the basis of the apparently constant disparate distribution of *in situ* chalcedony, calcite or barite concretions and highly polished "gastrolith" pebbles. During the course of this study, the two were never found in positive *in situ* association. "Gastroliths" (hereafter referred to as polished pebbles or cobbles) were encountered only in the upper claystone (Unit VII), whereas chalcedony, calcite or barite concretions were never found above the level of Unit V. The two are frequently found in association on the surface, but this clearly is a secondary association due to concentration of polished pebbles on lower angle slopes beneath the usually steep exposures of Unit VII. Not a single chalcedony concretion was found on the surface above Unit V, nor were any concretions found in place in the nearly 60 fossil quarries that we excavated in Unit VII and the upper part of Unit VI. Polished pebbles, on the other hand, were frequently, although never abundantly, discovered in these excavations. It must be pointed out that only eight excavations were opened in Unit V, compared with nearly 60 above that Unit, so I must admit to the possibility that polished pebbles do occur below Unit VI. None were encountered, however, either in our excavations or in fresh rock exposed while measuring stratigraphic sections.

This apparently constant relationship not only constitutes the most reliable criterion for distinguishing the two upper claystones but also permits recognition of the two middle sandstones or conglomerates (Units IV and VI). Thus, the Pryor Conglomerate (Unit IV), which everywhere lies below a chalcedony-concretion-rich claystone, cannot be equated with the conglomeratic sandstone described by Darton at the base of his Cloverly type section which lies above a chalcedony-concretion-rich claystone. The boundary between the Cloverly and Morrison Formations in nearly all published reports has been placed at the base of a pebbly sandstone or conglomerate. Whether stated or not, the implication is that *the* sandstone selected corresponds to

Darton's basal Cloverly facies. The following discussion, together with the 28 measured sections at the end of this report (Appendix A), will show many of these correlations to be in error.

Specifically, whereas Darton (1906) described what I have here labeled as Unit VI as the basal clastic facies of the Cloverly Formation, Hares (1917), Bauer and Robinson (1923), Lee (1927), Knappen and Moulton (1930), Thom, Hall, Wegemann and Moulton (1935), Wilson (1936), Lammers (1939), Love et al. (1945), Gardner et al. (1946), Richards (1955) and Moberly (1962) have referred to a lower bed—my Unit IV (the Pryor Conglomerate of some authors)—as the lowest unit of the Cloverly Formation (Fig. 3). On the other hand, Hewett (1914), Ziegler (1917), Pierce and Andrews (1940), Pierce (1948), and Rogers et al. (1948) adopted the uppermost, transitional sandstones (rusty beds of Darton and others), or what I have here labeled as Unit VIII, as the basal Cloverly facies. In other words, depending on which of the three uppermost clastic units was present, or most prominent in the regions studied, all three upper sandstones (Units IV, VI and VIII) have been used as the basal Cloverly sandstone. Hintze (1915), Lupton (1916), Hewett and Lupton (1917), Lee (1927, in part), Thom, Hall, Wegemann and Moulton (1935, in part), Andrews and Eargle (1947) and Mirsky (1962a, b) seem to have adopted the same (or at least a similarly positioned) coarse sandstone as did Darton for the basal facies of the Cloverly Formation.

Our traverses have established that all three sandstones are discontinuous—and of doubtful correlation even when present. In contrast, the intervening, fine-grained facies appear to be not only widespread but continuous *and* distinctive. This applies particularly to Units V and VII, which constitute the greatest part of the Cloverly Formation as defined by Moberly (1960) and in this report. My opinion at this point is that claystone fractions of nonmarine sequences may be of far greater value in subdivision and correlation of continental strata than are the coarse sandstone facies that are more conspicuous and traditionally relied upon.

PREVIOUS STUDIES

The earliest investigations of these nonmarine strata are those of Darton (1904, 1906). In his first report, Darton compared the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range regions. In the Bighorn area he recognized lithologies that he considered to be the same as those of the Morrison Formation in Colorado and adjacent to the Black Hills. Overlying the "Morrison", he described (1904: p. 398) a "thin bed of sandstone which, from its stratigraphic relations and character, is believed to represent the Lakota of the Black Hills, overlain by and merging into clays resembling the Fuson formation . . . it has been thought best to give this series a separate designation. Accordingly, 'Cloverly' is proposed, a name derived from a postoffice on the eastern side of the Bighorn basin." No type section was cited and only the following general description was given (p. 398–399):

> The sandstone member of the Cloverly formation usually gives rise to a line of knobs or low ridges on the divide along the eastern slope of the Bighorn uplift. Ordinarily it is a coarse grained, buff or dirty gray, cross-bedded, massive sandstone, averaging 30 feet in thickness, but varying from 10-60 feet. The overlying

> clay is rarely exposed, but in a few outcrops it is seen to be a reddish to ash-colored clay, locally of darker gray color and with a thickness of from 30 to 40 feet.

Notice that this description was based on the exposure along the *east* flank of the Bighorn Mountains and that while it does correspond generally with the section exposed around the margins of the Bighorn Basin, the relationship to topography and the nature of the exposures are quite different. West of the Bighorns, the "basal sand" rarely forms ridges or topographic highs and commonly is concealed. The overlying claystone, on the other hand, is rarely concealed and usually forms steep, brightly colored, fluted slopes or cliffs.

Darton's original description of the Cloverly was followed in 1906 by a more extensive discussion of general features, a detailed section recorded in the vicinity of the Cloverly Post Office (Fig. 2), which we may consider the type section (see my Plate 1:A), and brief descriptions of the Cloverly Formation at a number of other sites in the Bighorn region. Following publication of Darton's 1906 report, a number of investigations were undertaken by others in other sectors of the Bighorn area, usually with reference to natural resources. Few of these were regional in scope, most dealt with only a limited area with little or no reference to adjacent areas. Many, in fact, merely cited Darton's findings (apparently without examination of his sections) in subdividing and labeling sections in their own areas. Because of the provincial nature of most of these earlier reports, the following discussion is similarly organized, treating local sectors separately within the total study area.

CLOVERLY-SHELL CREEK AREA. The Cloverly-Shell Creek area encompasses the central part of Big Horn County, Wyoming, and includes the outcrops along Shell Creek, around Sheep and Little Sheep Mountains and the extensive but discontinuous badlands extending in a northwest-southeast-trending belt between Shell Creek and the junction of the Bighorn and Shoshoni Rivers. Describing the Cloverly Formation along the west flank of the Bighorn Mountains, Darton (1906: p. 52) wrote: "In the vicinity of Cloverly the formation varies in thickness from 50 to 125 feet, and to the east and north of that place it consists of sandstones which outcrop extensively in cliffs of massive buff-colored beds, mostly of moderately coarse-grained material. To the west the middle and lower portions of this sandstone change to a maroon color and some clay is intermixed with the sand. This rock weathers into badlands." The section given by Darton (following page) was located 1.5 miles (2.4 km) west of Cloverly, Wyoming.

In his 1904 report, Darton defined the Cloverly Formation as consisting of a lower sandstone facies and an upper, brightly colored clay facies. He did not include an upper sandstone. In his discussion of the overlying Benton Formation, however, he described (p. 399) the basal member as: "dark gray shales, in part sandy and of rusty brown color with occasional thin beds of brown sandstone. Locally, the sandstone expands into a bed of moderate thickness. It is possible that this portion of the formation [Benton] represents the Dakota sandstone of other regions. . . ." In his 1906 report, Darton altered his original definition to include a massive or thinly bedded sandstone overlying the bright clay member of the Cloverly Formation, this in turn being overlain by a "rusty series" of the Benton Formation. Regarding correlation he wrote (p. 53): "The Cloverly formation is believed to represent the Lakota sandstone, Fuson formation and Dakota sandstones of the Black Hills region."

This report	Darton's report	
Unit VIII:	Light-buff sandstone (overlain by Benton shale)	10 feet
	Tan-colored sandstone	10 "
Unit VII:	Maroon clay	4 "
	Reddish and tan-colored sandy clay	10 "
	Drab sandy clay	10 "
	Deep maroon sandy clay	20 "
	Hard tan-colored sandstone	3 "
	Deep maroon to purple variegated clay	12 "
	Lenses of maroon sandstone	3 "
	Deep maroon sandy clay	20 "
Unit VI:	Olive-green, soft, cross-bedded sandstone with hard layers (lying on maroon and drab-gray Morrison shale)	11 "
	Total	112 " [*sic*]

Fisher (1906), working under Darton's direction, relied on the latter's sections along the eastern side of the Basin, simply quoting Darton's descriptions of sections. Washburne (1908, 1909) thought the basal sand and middle clay members of the Cloverly were absent at many localities and attributed this to erosion prior to deposition of the "rusty beds". In discussing the gas-producing horizon in the Basin-Greybull area, Washburne (1908: p. 350) wrote:

> The "rusty beds" are a constant feature of the base of the marine Cretaceous. Seemingly they are as a group a true basal sandstone, resting upon a rather smooth surface of erosion. Beneath this erosional surface at some localities is a heavy sandstone, probably the lower sandstone of the Cloverly formation; but at most places the Cloverly sandstone is absent and the "rusty beds" rest upon maroon, pink, or bright-green shales which are regarded as part of the Morrison formation, though they may belong to the Cloverly. There can be no doubt as to the lenticular nature of the Cloverly sandstone and its absence over most of the area. The field evidence indicates that the sandstone was removed by erosion before the deposition of the overlying marine strata of the Upper Cretaceous.

The "lenticular sandstone" (Unit VI) is absent locally; for example, at several points in the extensive exposures between Bear Creek and North Fork Beaver Creek some 3 to 5 miles (4.8 to 8 km) north of the former Cloverly Post Office site, locally along the Cherry Anticline south of Shell Creek, in certain exposures west of Thermopolis and at several localities in the Beauvais Creek area of the Crow Indian Reservation. In the immediate vicinity of Cloverly, to the south at Shell Creek Dome and in the badlands along the south side of Shell Creek, this "basal Cloverly sand" is ever present, although it varies from less than 3 to more than 30 feet (0.9 to 9.0 m) thick. The field evidence mentioned (but not identified) by Washburne, which supposedly indicated that this sand was removed prior to deposition of the marine (Thermopolis) sequence, was never recognized by us, for whether or not the "basal Cloverly sand" is present, the brightly colored, polished pebble-bearing claystone (Unit VII) is present everywhere within the study area beneath the sandstone (Unit VIII) of the "rusty series". Thus Washburne's second thought that the maroon shales beneath the "rusty beds" possibly belong to the Cloverly Formation would seem to be correct. Washburne repeated his interpretation in 1909 (p. 168) at the conclusion of his description of the section near the Montana state line: "In all other places examined none of the [Cloverly] formation above the basal sandstone is certainly present, and in most places the entire formation is absent. This hiatus is due to an unconformity separating the Cloverly formation from the overlying marine Colorado shale."

This statement is contrary to our findings. During the course of the present investigation, the entire outcrop belt of the Morrison-Cloverly sequence was walked out in the area shown in Figure 2. Throughout this area the "rusty series", with or without a massive sandstone at its base, lies on variegated, maroon to red-brown or purplish claystone rich in polished pebbles (Unit VII). This in turn lies on either a massive, cross-bedded sandstone up to 70 feet (21 m) thick (Unit VI), or on drab, chalcedony-concretion-rich, bentonitic claystone (Unit V). Contrary to Washburne's interpretation, we found no evidence to substantiate a post-Cloverly, pre-Colorado (Thermopolis) erosion surface in this area. Local absence of Unit VI is attributed to lack of deposition rather than erosion, for Unit VII is universally present in this vicinity.

Hintze (1915), who formalized the term Greybull sandstone, described (p. 14–15) the Cloverly Formation in the Shell Creek area as consisting

> of sandy shales and clays, often brightly colored, tan, maroon, or purple, lying between two sandstone members, in typical section. It is to be noted, however, that the upper one of the sandstones is often wanting, and in such sections the outcrop is apt to be less conspicuous. This condition is noticeable on the south side of Shell Creek three miles east of the Sheep Mountain section above referred to, where the "Rusty Beds" of the lower part of the Colorado rest directly upon the variegated shales and clays of the central part of the Cloverly. The absence of the upper sandstone may be due to nondeposition or to erosion previous to the deposition of the Colorado sediments. . . .

The absence of a massive sandstone at the base of the "rusty beds" (usually labeled as the Greybull sandstone) was noted at a number of sites west of Cloverly, along Crooked Creek near the Montana state line, and particularly within the Crow Indian Reservation. It appears that this unit grades laterally from a massive sandstone to thinly bedded strata interbedded with thin laminae of fissile, black shale. Hintze, however, accounted for the absence of the upper massive sandstone by a pre-Colorado erosion episode in accordance with Washburne's suggestion.

The term Greybull sand, long used by drillers to refer to the gas-producing horizon in various fields along the eastern margin of the Bighorn Basin, was first formally applied to surface exposures by Hintze (1915: p. 15), who identified it with the prominent sandstone at the base of the "rusty series" in the Basin-Greybull area. Subsequent studies of surface geology have generally followed this usage, but identification of the Greybull sandstone in subsurface appears to have been inconsistent. The usual practice seems to have been to apply this term to the first massive sandstone below the Muddy Sandstone Member of the Thermopolis Shale, whether it was one of the discontinuous sands within the lower Thermopolis, a sand at the base of a "rusty series" (Unit VIII), or the "basal Cloverly sand" (Unit VI).

Hewett and Lupton (1917: p. 68) referred to only one section in this area, giving a brief description of the exposures in Shell Creek Dome. They list 25 feet (7.5 m) of conglomeratic sandstone, 75 feet (21.5 m) of variegated red "shale" and 25 feet (7.5 m) of upper sandstone, referred to as the Greybull sand, in their Cloverly Formation. These correspond to Units VI, VII and VIII (see Chart 1) of our section at Shell Creek Dome (Section 12 of Fig. 4).

Lee (1927: Pl. 2) described a section measured 2 miles (3.2 km) west of the former Cloverly Post Office site, near Darton's type section. His section corresponds closely to that of Darton, except that it is slightly thicker (see Chart 1). Lee recorded the "basal Cloverly sand" as 35 feet (10.6 m) thick (compared with Darton's 11 feet) and the overlying variegated claystone member, including a 10 foot sandstone, as 105 feet (32 m) (compared with Darton's figure of 82 feet). We found exposures which closely approach Lee's description approximately 1 mile (1.6 km) north of the small reservoir on Beaver Creek (see Plate 1:A). Of particular importance here is Lee's notation that he did not observe a lower "brown conglomeratic sandstone" below the "basal Cloverly sandstone" such as he observed in exposures near Hyattville (p. 62) and Thermopolis (p. 59). However, we found just such a lower conglomeratic sandstone (Section 14 of Fig. 4) about 3.5 miles (5.6 km) east of the type exposures, which is indistinguishable from the Pryor Conglomerate. This latter unit, with its abundant black chert pebbles, has tentatively been labeled Unit IV.

The absence of a second or lower conglomeratic sandstone in the type area may be a significant contributory factor in the conflicting placements by various students of the Morrison-Cloverly boundary throughout the Bighorn area. To the north, the base of the Cloverly is most frequently placed at the base of the Pryor Conglomerate, which lies well below the level of Darton's basal sandstone. On the west side of the Basin, the boundary is placed at the base of the most prominent conglomerate, or in the absence of a conglomerate, at the top of the variegated claystones. In the south, if a conglomerate is present, the boundary is placed there; otherwise it may be placed almost anywhere in the variegated claystone sequence. I think it is important to note here that while Darton did describe his basal sandstone member as conglomeratic at certain localities, he did not describe it as such in the Cloverly type area. The type basal sand can be traced to sites where it is conglomeratic, but clearly it is not persistently conglomeratic, nor is it continuous. It is also important, and unfortunate, that most of the continental section below Darton's basal Cloverly sand is no longer exposed at the type section (a small dam across Beaver Creek has flooded this critical spot). However, a complete section is exposed in the twin buttes approximately 3.5 miles (5.6 km) to the east and here a Pryor-like conglomerate 18 feet (5.5 m) thick is well exposed approximately 100 feet (30 m) below Darton's basal sand. This exposure is perhaps the most critical evidence indicating that the Pryor Conglomerate and Darton's basal Cloverly sandstone are not identical (see Sections 13 and 14 of Fig. 4).

A second section recorded by Lee (1927: Pl. 2) is located 8 miles (12.8 km) northwest of Greybull on the west limb of the Sheep Mountain Anticline. This is in the vicinity of Section 17 given at the end of this report (Appendix A). In this section, Lee assigned 293 feet (94 m) (+ 100 feet of overlying Greybull sandstone) to the Cloverly Formation and 260 feet (79 m) to the Morrison; the total is more than 250 feet (76 m) thicker than we observed for the nonmarine section anywhere in this area. The uppermost 35 to 95 feet (9.5 to 30 m) of variegated claystone of Lee's section are here equated with Unit VII, the underlying 200 feet (61 m) with Unit V. Lee's 260 feet of "Morrison" may correspond with the lower part of Section 17 (Fig. 4), which may be either Unit III or I (Chart 1).

A very different usage is given by Pierce (1948) in his geologic map of the Basin-Greybull area. Pierce does not separate the Morrison-Cloverly sequence, but in his columnar section he includes the Greybull sandstone as the *lower* member of the Cloverly, with the overlying "rusty beds" composing the remainder of this Formation (Chart 1).

Moberly (1960), in the most recent and comprehensive stratigraphic analysis of this sequence, redefined the Cloverly Formation to include the underlying 150 to 300 feet (45 to 90 m) of sandstones and claystones beneath Darton's type Cloverly, restricting the Morrison Formation to the lowermost ± 200 feet (61 m) of nonmarine sediments overlying the Sundance Formation. In general terms, Moberly's new alignment compares with Darton's 1906 classification and that used here as follows:

Darton, 1906	*Moberly, 1960*	*This Report*
"Dakota-like" sandstone + "rusty beds"	Sykes Mountain Fm.	Unit VIII + "rusty beds"
Variegated middle claystone member, Cloverly Fm.	Himes Member of the Cloverly Formation	Unit VII
Basal sandstone member of the Cloverly Formation	"Lithic wacke" of the Himes Member, Cloverly Fm.	Unit VI
Morrison Formation (part)	Little Sheep Mudstone Member, Cloverly Fm.	Unit V
Morrison Formation (part)	Pryor Conglomerate Member, Cloverly Fm.	Unit IV
Morrison Formation (part)	Morrison Formation	Units I, II, III
Sundance Formation	Sundance Formation	Sundance Formation

Moberly (1960: p. 1142) justified this expansion of the Cloverly Formation on the following grounds:

> A formation is a genetic lithic unit, and because of its genetic and economic significance, lithic constitution of a sequence is fundamental to subdivision into formations. Frequently, expediency for mapping an area has determined which lithic characters are selected for determining formational boundaries. However, as understanding the origin of a series of sedimentary rocks becomes of more value in the historical interpretation of an area, lithologic characters of greatest genetic significance, rather than those most easily mapped, must be selected for the determination of a formation.

But for the final remark, I would agree with most of Moberly's statement. Rock units, to varying degrees, reflect their genesis, and genetic characters may, and should, be utilized when establishing formal stratigraphic units. But the purpose of formalizing a stratigraphic sequence into formations and members is not to define paleoenvironments any more than it is to establish rock ages; it is to classify or separate a variety of lithic entities into practical, easily identifiable units. The fundamental objective is identity—the clear, unmistakable identification by everyone concerned. Formalization of a stratigraphic sequence, to this end, requires that it be based on the most conspicuous, reliable and persistent features available, whether or not they have recognized significance for any particular hypothesis of origin or theoretical lithotope.

As noted earlier, my objective in these discussions is to equate our stratigraphic sections and the precise levels of the vertebrate fauna with the stratigraphic interpretations of others. It is unfortunate that so few of the early reports include detailed measured sections (or precise locations for sections), for without these data it is impossible to arrive at an accurate equation. In the absence of detailed sections, the reader is forced to guess at the data that are the bases of an author's interpretations and stratigraphic subdivisions. Chart 1 summarizes part of the above discussion by equating the few published sections from the Cloverly-Shell Creek area with the major subdivisions of the Morrison-Cloverly sections used in this report. These are based on observations made at the section sites mentioned or in the immediate vicinity of those sections.

A total of seven localities (Locality Maps D, E, F and G) were discovered in the general area of the Cloverly Post Office site, Shell Creek valley, and Sheep and Little Sheep Mountains, which produced fragmentary but identifiable fossil vertebrate material. These materials are reported in the following section on systematic paleontology. Three of these localities (YPM 62-4, 62-5 and 62-6) are situated in the extensive outcrop area south of Shell Creek. Two of them occur in the lower part of Unit VII, from 5 to 15 feet (1.5 to 4.5 m) above its base. The third (YPM 62-6) is in Unit V approximately 30 feet (9 m) below the base of Unit VI. A fourth site (YPM 62-10) is situated at the south end of Sheep Mountain Anticline and is in Unit VI approximately 10 feet (3 m) above its base. Three more localities (YPM 62-11, 62-12 and 62-13) are located approximately 18 miles (29 km) west of the Cloverly Post Office site on the south limb of Little Sheep Mountain Anticline near Himes, Wyoming (Locality Map G). All three lie in the upper 2 or 3 feet (0.6 to 0.9 m) of Unit VII. In addition, a number of other localities were recorded in this area, particularly west of "Cloverly", south of Shell Creek and along both east and west flanks of Sheep Mountain, where abundant bone fragments were weathering out of the middle and lower parts of Unit V. No collections were made at these sites because exploratory excavations indicated that these bone concentrations were surface lag accumulations, the resistant residue left after removal of the bone-bearing claystone.

The American Museum's famous Howe Quarry (Brown, 1933, 1935) lies within this area in NE ¼ sec. 9, T.54 N., R.91 W., (see my Fig. 2), and because Brown reported this site to be within the Cloverly Formation, it was carefully checked during our first field season. Exposures are poor and discontinuous in the area and faulting or slumping has disturbed the section sufficiently to make precise correlation difficult and uncertain. However, on both lithic and stratigraphic grounds I have concluded that the Howe Quarry lies well below the Cloverly Formation, and at least 150 feet (45 m) below Unit VI. Comparison with the Cedar Creek Section (measured Section 14 of Fig. 4), 1.5 miles (2.4 km) to the southwest, places this site near the middle of the lower claystone sequence (Unit III or I?), approximately 40 feet (12 m) below Unit IV. If the latter Unit is correctly identified as the Pryor Conglomerate, the Howe Quarry falls outside of the Cloverly (contrary to Brown's [1933] statement), regardless of whose usage is adopted. This placement appears to be consistent with the materials collected there. The Howe Quarry collection is not given detailed analysis here, but the collections made there consist entirely of sauropod remains that are referable to Morrison taxa *Camarasaurus* and *Diplodocus.*

HYATTVILLE-TENSLEEP-NOWOOD CREEK AREA. This region includes the southern part of Big Horn County and the central part of Washakie County. Outcrops parallel Nowood Creek from the northern county boundary to the common corner of Washakie, Hot Springs and Fremont Counties. In the north they form a long ridge along the west limb of Cherry Anticline. Badland type exposures are rare in this area, most outcrops occurring in low cuestas or prominent hogbacks. Darton (1906) was the first to consider the Morrison-Cloverly section in this area, describing (p. 52) the Cloverly Formation at three localities as follows:

> On Nowood Creek, south of Tensleep, the formation consists of a massive light-colored sandstone about 40 feet thick, overlain by 30 to 60 feet of light-colored shale, mostly massive, and at the top a thin bed of buff to reddish-brown sandstone 8 to 10 feet thick. A mile west of Tensleep the basal sandstone is nearly pure white in color, coarse grained, and cross-bedded. The overlying shale and clay are 60 feet thick and at the top are 8 feet of sandstone varying in color from white to buff and brown. In the vicinity of Hyattville the following members are exposed: At the base 40 feet of buff cross-bedded sandstone overlain by 130 feet of clays, reddish near the bottom, greenish and sandy higher up, maroon toward the top, and gray and sandy at the top. These clays are overlain by a 15 foot bed of hard, buff, partly massive sandstone succeeded abruptly by dark Benton shales with thin, brown sandstone layers.

The first two sections coincide with our observations in those areas, the units mentioned corresponding to Units VI, VII and VIII (Chart 2). The section at Hyattville, however, is interpreted differently here (Section 10 of Fig. 4). Within the 130 foot (39 m) claystone sequence mentioned by Darton, we found the lower 36 feet (11 m) consisted of pale-maroon to gray calcareous claystone apparently lacking in chalcedony concretions. This is overlain by 38 feet (11.6 m) of brightly colored, variegated, red, deep-maroon, red-brown and gray claystone, partly bentonitic, with frequent chalcedony concretions. The upper 35 to 40 feet (11 to 12 m) is very similar to the underlying claystone except that chalcedony concretions were not found, whereas polished pebbles are common, although not abundant. The universal absence of chalcedony concretions above the level of Unit V elsewhere in the study area, and the apparent restriction of polished pebbles to claystones above this level, suggests that Darton's Cloverly claystone in the Hyattville area includes both Units V and VII, and that the lower 30 to 40 feet (9 to 12 m) overlying his "basal sandstone" may represent Unit III. At some exposures, particularly to the south and west of Hyattville, a thin, 1 to 6 foot (0.3 to 1.8 m), medium-grained, quartz-feldspar sandstone occurs approximately 35 to 50 feet (10.5 to 15 m) below the top of the claystone sequence. This may be a local wedge of Unit VI. The "basal sandstone" described by Darton in the Hyattville area, lying below a chalcedony concretion zone, appears not to correlate with his basal sandstone in the type exposures; lithologically it is very similar to the lowest prominent sandstone in the Thermopolis area (Unit II). On these grounds it is tentatively correlated with that Unit.

Hewett and Lupton (1917) provide only the briefest general description of the Morrison-Cloverly sequence (p. 19) together with occasional comments on exposures in various anticlinal structures in this area. Referring to exposures in Paintrock, Mercer, Nowood and Bud Kimball Anticlines (p. 85, 91, 99 and 117–118), they note a uniform thickness of 125 feet (38 m) for the Cloverly Formation and 200 to 250 feet (61 to 76 m) for the Morrison. The latter is described simply as variegated "shales" and sandstones, the Cloverly as consisting of upper and lower sandstones, both 20 to 25 feet (6 to 7.5 m) thick (the lower one usually conglomeratic) and a middle variegated shale 75 to 80 feet (23 to 24.5 m) thick. Although we did not find the section to be so uniform, the comments generally agree with our findings at these structures. For example, at Bud Kimball Anticline south of Tensleep we measured the lower conglomeratic sandstone (Unit VI) as 55 feet (16.5 m), the middle claystone, which contains abundant polished pebbles, as 35 feet (10.5 m) and the upper sandstone (Unit VIII) as 5 to 10 feet (1.5 to 3 m). At Paintrock Anticline the upper "gastrolithic" claystone (Unit VII) is 45 to 50 feet (13.5 to 15 m) thick and underlain by a 4 to 6 foot (1.2 to 1.8 m) sandstone that I believe represents Unit VI. Beneath this is 125 to 135 feet (38 to 41 m) of variegated claystone (Unit V), 45 feet (13.5 m) of coarse, light-tan sandstone (Unit II?) and 175 feet (53.5 m) of drab, gray-green claystone and sandstones (Unit I). Throughout their report, Hewett and Lupton apply the term Greybull sandstone to the sandstone at the base of the "rusty series", but they make an erroneous reference (p. 19) to the "Greybull sandstone" illustrated in their Plate IVA, which they describe as lying unconformably on "variegated shales of the Morrison Formation near Tensleep". The sandstone illustrated, however, is the basal sandstone (Unit VI) of Darton's Cloverly and is overlain by brightly colored, variegated, polished pebble-bearing claystone (Unit VII)—not the "rusty series".

Lee (1927: p. 60–62) included descriptions of sections at Nowood, Tensleep, Hyattville, near Bonanza Anticline and north of Hyattville (Mercer Anticline?) (see my Chart 2). His description of the Cloverly section at Nowood, approximately 30 miles (48 km) south of Tensleep, matches my Units VI, VII and VIII, but Lee omits information about the thickness of his "Cloverly members", thus these correlations cannot be verified. Lee's Tensleep section lists a 70 foot (21.3 m) conglomeratic basal Cloverly sandstone, a 30 foot (9.1 m) middle "shale" member and 10 ± feet (3 m) for the upper (Greybull) Cloverly sandstone. These have been identified as Units VI, VII and VIII, although we obtained slightly different thicknesses. For some unexplained reason, the above description does not match Lee's Tensleep column (Pl. 2) which lists these units at 45, 63 and 9 feet (13.5, 19.2 and 2.7 m), respectively. Of particular interest is Lee's reference (p. 61) to a second conglomerate 7 feet thick beneath his "basal Cloverly sandstone", which he judges as *not* part of the Cloverly Formation but corresponding to the coal-bearing part of the Kootenai. He does not attempt to equate this with a similar but thicker lower conglomerate that he (and we) noted 3.5 miles (5.6 km) northeast of Thermopolis, although this is an obvious possibility. The fact that Unit V is apparently absent in exposures in the Tensleep vicinity (see Section 9, Fig. 4) may be significant and appears to lend support to this latter interpretation. Except that it is significantly coarser grained and less brilliant white in color, I could find no evidence for separating the lower 6 to 12 feet (1.8 to 3.6 m) from the overlying 40-odd feet (12 m) of sandstone at this site, but it is entirely possible that this prominent massive unit represents both Units IV and VI of our classification. Lee's descriptions of the Cloverly exposures immediately south of Hyattville seem to correspond to elements that we labeled VI, VII and VIII (Section 10, Fig. 4), but again he provided no thicknesses. North of the Bonanza Anticline, probably in the north end of the Paintrock Anticline, Lee estimated the lower Cloverly sandstone at more than 100 feet (30 m) thick and the "red, sandy shales containing many polished pebbles or 'stomach stones' " at about 200 feet (60 m) thick. Overlying these he listed a 5 to 15 foot (1.5 to 4.5 m) sandstone (Greybull). We did not record a section at this locale, but at no place in the Paintrock Anticline did we encounter thicknesses for these units of more than 50 and 135 feet (15 and 41 m), respectively. At this area, Lee again noted a brown conglomerate (which he compared with that near Thermopolis) 1 to 10 feet (0.3 to 3.0 m) thick, overlain by a carbonaceous shale, lying beneath his "lower sandstone member of the Cloverly". I have tentatively identified it as Unit IV, correlating it with the Pryor Conglomerate to the north. In exposures 1 or 2 miles (1.6 to 3.2 km) to the south near Paintrock Creek, we found no sign of this lower, dark conglomerate. Furthermore, we found that only the upper 45 to 55 feet (13.5 to 18.5 m) of the variegated claystone sequence definitely represented Unit VII; the underlying 125 to 135 feet (38 to 41 m) of claystone is rich in chalcedony concretions and thus represents Unit V (and perhaps part of Unit III). No chalcedony concretions were found either above or below Lee's "100 foot thick" Cloverly sandstone at the north end of this anticline, but polished pebbles are infrequently present in the overlying claystones. On this basis, Lee's Cloverly Formation here is equated with Units VI, VII and VIII (Chart 2).

Another critical section is exposed in the Mercer Anticline approximately 6 miles (9.6 km) northwest of Hyattville. Lee (1927: p. 62) described the section in a small dome (not identified by name, but presumed to be the above structure) in this locale as follows:

> Here a brown conglomerate consisting chiefly of pebbles of chert and ranging in thickness from 1 to 25 feet rests on variegated shale of the dinosaur-bearing Morrison formation. Above the brown conglomerate is a brown to black shale 5 to 20 feet thick containing carbonized plant remains and thin seams of brown lignite. The variation in thickness seems to be due to erosion, for the overlying conglomeratic sandstone rests on the shale with sharp irregular contact. . . . The higher conglomeratic sandstone is gray, massive, and cross-bedded and is 50 feet or more in thickness. It is the lower part of the Cloverly of northern Wyoming and is the lower conglomeratic sandstone of the group of rocks which the writer correlates with the Dakota group of Bellvue, Colo.

Overlying the upper conglomeratic sandstone is 50 to 65 feet (15 to 20 m) of variegated claystone locally rich in polished pebbles that we identified as Unit VII, capped by massive and thinly bedded, buff to rusty-brown sandstone (Unit VIII). Exposures in the Mercer Anticline are generally poor, but we found no evidence of chalcedony concretions in the area, indicating that Unit V probably is absent here. Moreover, the upper conglomeratic sandstone could not be traced to other exposures north and south, between Shell Creek and Hyattville. However, I believe Lee's interpretation is correct and have assigned this sandstone to Unit VI. Thus Lee's interpretation of the Cloverly in the Mercer Anticline corresponds to Units VI, VII and VIII of our classification. The underlying lignitic shale and lower, brown conglomerate resemble very closely the sections in the north end of Paintrock Anticline and 3.5 miles (5.6 km) northeast of Thermopolis (see Section 6 of Appendix A and Fig. 4). At all three sites this conglomerate is characterized by black, dark-gray or brown chert and gray and brown quartzite pebbles. The sand fraction is also predominantly dark chert and quartzite. The resemblance to the Pryor Conglomerate is evident; accordingly, it is here designated Unit IV. It should be apparent to the reader that this part of the section also seems to correspond to part of the Tensleep section as interpreted by Lee. The sequence below this "Pryor-like" conglomerate is very poorly exposed in the Mercer Anticline, but presumably it represents either or both Units I and III.

Rogers et al. (1948), in their geologic map of the Worland-Hyattville area do not designate a specific boundary between the Morrison and Cloverly Formations, although they do list the "Greybull sandstone" ("5 to 70 feet of light-gray to brown resistant sandstone") as the *lower* member of the Cloverly! They describe the "Greybull sandstone" as being overlain by "sandstone, siltstone and shale and several thin, interbedded ironstone or 'rusty beds' " and underlain by a sequence of gray, red and light-purple claystone and shale and interbedded brown, lenticular sandstone containing the so-called gastroliths. From this description it is clear that their "Greybull sandstone" corresponds to our Unit VIII, and that their Cloverly Formation (they list 125 feet [38 m]) consists chiefly of the overlying "rusty series". Their Morrison Formation thus includes our Unit VII and all underlying nonmarine elements.

Moberly (1960) extended his redefined Cloverly Formation (equaling Units IV, V, VI and VII) to the vicinity of Hyattville, but no specific sections were described from this area (see Chart 2 for a summary of these previous interpretations).

Mirsky (1962a and 1962b) has presented the most detailed stratigraphic sections within this area. His initial contribution contained 20 measured sections, 6 of which are located in the Morrison-Cloverly outcrop belt between Nowood and Tensleep. These latter sections are duplicated in Chart 2 and correlated with the terminology used in this report, based on our examination of exposures in the vicinity of Mirsky's sections. The same 20 sections form the bases of Mirsky's more extensive paper on the stratigraphy of nonmarine Upper Jurassic and Lower Cretaceous strata (1962b) along both east and west flanks of the Bighorn Mountains.

In brief, Mirsky recognized four major units, which he believed to be the same basic units recognized by Darton (1904). They are a lower, variegated mudstone, which Mirsky considered to be the Morrison Formation; a white to gray, cross-bedded sandstone, which he formalized as the Otter Creek Sandstone member of the Cloverly Formation; an upper, variegated mudstone, which he identified as the upper member of the Cloverly Formation (including an overlying sandstone); and an uppermost sequence of interbedded black shales and thin sandstones ("rusty series"), which he considered to be the basal strata of the Thermopolis Shale. Mirsky's first unit, which varies from 210 to 265 feet (64 to 80.5 m) thick, corresponds to Units I, II?, and III of this report. The Otter Creek Sandstone corresponds to Unit VI, although there is some doubt as to whether or not this is the same as Darton's type basal Cloverly sandstone. The lower part of Mirsky's mudstone member of the Cloverly corresponds to our Unit VII, and the upper sandy part of that member is equated with our Unit VIII. Thus Mirsky's Cloverly Formation here corresponds to Units VI, VII and VIII.

The Otter Creek Sandstone occupies the same stratigraphic position as the basal sandstone described by Darton at the type Cloverly exposures, but it cannot be demonstrated that it is the same unit. Lithologically it is quite different from Unit VI in the area north of Shell Creek, but it closely resembles the upper of two middle sandstones at Thermopolis. In the outcrops between Tensleep and Thermopolis, the chalcedony-rich claystone (Unit V) is absent and the Otter Creek Sandstone lies disconformably on rather drab, calcareous and sandy claystone. At Tensleep, it is underlain by 6 to 12 feet of gray, conglomeratic sandstone that resembles the Pryor Conglomerate (Unit IV) of more northerly exposures. At Thermopolis (Sections 5 and 6 of Fig. 4), a thick sandstone resembling the Otter Creek Sandstone is underlain by a similar, dark-gray conglomerate that I have tentatively labeled as Unit IV, and which very closely resembles the Pryor Conglomerate. Certainly it is significant, I think, that a Pryor-like conglomerate occurs at the appropriate level in exposures at Mercer and Paintrock Anticlines, and at Tensleep (also Thermopolis), as well as near the type Cloverly exposures. Elsewhere between Thermopolis and the type Cloverly area this conglomerate (Unit IV) is absent, as is Unit V—the overlying chalcedony-rich claystone. In the vicinity of Nowood Creek at least there appears to be a parallel absence of Units IV and V. Correlated with this is the presence of a thick, coarse sandstone (Otter Creek Sandstone). It appears the absence of Units IV and V is the result of extensive erosion prior to or at the time of deposition of the Otter Creek Sandstone. There does not appear to be a significant angular discrepancy between strata above and below this level, but more data are required.

Only two fossil vertebrate localities were found in the Hyattville-Tensleep area (Locality Maps B and C). The first (YPM 66-3) is located approximately 2 miles (3.2 km) southeast of Hyattville in gently dipping exposures north of Cedar Mountain. The stratigraphic level could not be determined precisely, but it is clearly within the limits of Unit VII at least 30 feet (9 m) below Unit VIII. Locality YPM 66-4 is in the southern end of Paintrock Anticline, approximately 6 miles (9.6 km) southwest of Hyattville. Again, the low angle of dip and the breadth of exposures made precise stratigraphic placement uncertain, but there is no doubt that it lies within Unit VII.

THERMOPOLIS AREA. This area includes the central part of Hot Springs County, Wyoming. Outcrops of the Morrison-Cloverly section are limited to a sinuous cuesta flanking the Owl Creek Mountains and the Thermopolis and Warm Springs or Red Springs Anticlines. Interpretation of the stratigraphy in this area poses many questions, for exposures, although common, are discontinuous and often partly covered. Moreover, the Cloverly-Morrison sequence here is more variable and includes facies not represented (or recognized) in other areas. However, most of the eight major units have been identified.

Fisher (1906) was the first to describe the Mesozoic strata exposed along the north flank of the Owl Creek Mountains, but his brief description of a Cloverly section at the west end of the Thermopolis Anticline is not adequate for comparison with sections recorded by others or observed by us. Fisher's 1908 report contained a more detailed section that he measured 3.5 miles (5.6 km) north of Thermopolis (probably not far from the site of measured Section 5 of this report). In his 1908 section (p. 85–86), Fisher recorded 40 feet (12 m) of variegated "shale" (Unit VII) beneath

24 feet (7.3 m) of thin-bedded and massive sandstones and blue, drab "shale" (Unit VIII). The variegated "shale" rests on 38 feet (11.5 m) of massive, light-colored, cross-bedded, conglomeratic sandstone (Unit VI), which in turn lies on 59 feet (17.8 m) of greenish-brown "shale" (Unit III?). Beneath this, according to Fisher, lie 130 feet (39.6 m) of yellowish-gray, massive sandstone (Unit II). Fisher included this entire section, totaling 290 feet (88.5 m), in the Cloverly Formation (Chart 3).

Hewett and Lupton (1917: p. 138) gave extremely brief descriptions of the Morrison and Cloverly Formations as exposed in Red Spring (Warm Springs?) and Lucerne Anticlines. Their Cloverly Formation appears to correspond to Units VI, VII and VIII of this report, but their descriptions are not adequate for detailed comparisons.

Lee (1927: Pl. 2 and p. 58), in a section located 2 miles (3.2 km) northwest of Thermopolis, recorded 42 feet (12.7 m) of conglomeratic basal Cloverly sandstone (Unit VI), 82 feet (25 m) of variegated claystone (Unit VII) and 60 feet (18.3 m) of ripple-marked, rusty-brown sandstone (Unit VIII). Three and a half miles (5.6 km) north of Thermopolis, Lee registered (Pl. 2 and p. 58) a 90 foot (27.5 m) thick conglomeratic, basal (Cloverly) sandstone (Unit VI and possibly IV), overlain by 55 feet (16.5 m) of red and bluish sandy "shale" (Unit VII), topped by 53 feet (16 m) of thinly bedded sandstones interbedded with variegated "shales" (Unit VIII). A mile (1.6 km) to the east of this last section, Lee noted (p. 59) 25 feet (7.6 m) of brown chert pebble conglomerate (Unit IV) and 20 feet (6.1 m) of carbonaceous shale with plant remains, beneath a 75 foot (22.8 m) thick conglomeratic sandstone (Unit VI) that he correlated with the basal Cloverly sandstone of exposures to the west. Notice that this section correlates almost unit for unit with the sections described earlier at Paintrock and Mercer Anticlines, and possibly with Lee's interpretation of the exposures 1 mile (1.6 km) west of Tensleep (see Section 6 of Appendix A and Fig. 4). These three sections, together with exposures in the type Cloverly area, are considered critical for correlation of the eight listed major units around the margins of the Bighorn Basin.

J. D. Love and others (1945) published a series of stratigraphic columns of the Lower Cretaceous and nonmarine Jurassic rocks in central Wyoming that included a column measured approximately 4 miles (6.4 km) north of Thermopolis. The column included some 18 feet (5.5 m) of variegated claystone (Unit VII) beneath the "rusty beds", underlain by a massive 25 foot (7.6 m) thick conglomeratic sandstone (Unit VI) resting on more than 50 feet (15 m) of variegated claystone. The claystone overlies some 38 feet (11.5 m) of conglomeratic sandstone (Unit IV?) resting on light and dark-green siltstones (Unit III?). This rests on 150 feet (45 m) of massive gray sandstone (Unit II). It appears likely that Love's lower conglomeratic sandstone is the same as the lower, brown chert pebble conglomerate of Lee's third section, and the one noted by us at the sites of measured Sections 5 and 6. Love et al. did not subdivide the nonmarine section, but they noted a zone of "sparkly, clean, porous, soft sandstone with lenticular chert pebble conglomerate" and related this to a quartz crystal sandstone at the base of the Cloverly in areas outside the Bighorn Basin. The suggestion is made that the base of this quartz sandstone may represent the contact between the Morrison and Cloverly Formations here.

It is evident from these reports that two conglomeratic sandstones occur at least locally in the Thermopolis area (one locale at which the lower of these is absent is

Warm Springs [Red Springs?] Dome approximately 10 miles (16 km) east of Thermopolis, as noted by Lee), separated at some places by 10 to 50 feet (3 to 15 m) of drab-green, lignitic claystone. At exposures on the west side of U. S. Highway 20, approximately 3.5 miles (5.6 km) north of Thermopolis, we found both of these conglomerates represented (but not separated) although they apparently were not recognized by either Fisher or Lee, both of whom recorded measured sections in this immediate vicinity. The intervening claystone is absent at these outcrops, but as recorded in Section 5 (Fig. 4), the lower 15 feet (4.5 m) of the prominent massive sandstone facies weathers dark gray to brown and consists largely of black and brown chert pebbles up to 1 inch (2.5 cm) in diameter—identical to the lower conglomerate exposed less than a mile (1.6 km) to the east across the Bighorn River. The overlying 35 feet (10.6 m) of sandstone weathers white to tan, is conglomeratic in its lower third with pebbles predominantly of light-colored quartzite and white chert—identical with the upper conglomerate across the river. This upper conglomerate is interpreted here as the "basal Cloverly sandstone" (Unit VI) and may also be correlated with the Otter Creek Sandstone Member of Mirsky (1962b). The lower one, on both lithologic and stratigraphic grounds, appears to correspond to the Pryor Conglomerate of more northerly exposures and is here labeled Unit IV.

The chalcedony-rich claystone facies (Unit V), which occurs between two very similar conglomeratic sandstones to the north in Big Horn County, is absent in the Thermopolis area and in outcrops to the east and north at least as far as Hyattville (it occurs locally in Paintrock Anticline and exposures immediately south of Hyattville [see Section 10 of Fig. 4], but not in Mercer Anticline northwest of Hyattville). But, Unit V is everywhere present in exposures west of Thermopolis and north of Mercer Anticline. Absence of Unit V in this area should not be considered reason for discounting the possible equivalency of the lower, chert pebble sandstone with the Pryor Conglomerate, for stratigraphic relationships in the Thermopolis area clearly indicate a significant erosion surface exists at the base of the upper conglomeratic sandstone (Unit VI), as suggested by Lee, (1927: p. 59, 62). The variable presence and thickness of carbonaceous shale between these conglomerates (see Lee's sections at Paintrock and Mercer Anticlines, and east of the Bighorn River at Thermopolis; also our Sections 5 and 6 of Fig. 4), support such an interpretation. It is probably significant that this erosion surface also correlates with the absence of Unit V and, at some places (Warm Springs Dome), Unit IV. It appears that removal of Unit V, part or all of Unit IV and perhaps the upper part of Unit III occurred during influx of the conglomeratic phase of Unit VI in the southeastern part of the Bighorn Basin. It is perhaps significant that in this area wherever Unit V (and sometimes Unit IV) is absent, Unit VI is usually conglomeratic and has near-maximum thickness (see Sections 5, 6, 7, 8 and 9 of Fig. 4). Wherever Unit V is present, Unit VI is almost always thin (or absent) and is rarely conglomeratic.

Section 5 of Appendix A (and Fig. 4), taken at the prominent exposures on the west side of U. S. Highway 20, 3.5 miles (5.6 km) north of Thermopolis, includes an upper, brightly colored, variegated claystone 67 feet (20.4 m) thick (with infrequent polished pebbles) lying between two coarse, buff sandstones, the lower one of which is conglomeratic. The latter is identified as Unit VI, the overlying "gastrolithic" claystone as Unit VII, and the uppermost sandstone is correlated with Unit VIII. At the base of the lower sandstone are 12 to 15 feet (3.6 to 4.5 m) of dark-gray, chert pebble conglomeratic sandstones. I interpret these as distinct from the overlying sandstone chiefly on the basis of identical facies separated from the overlying sandstone by 12 feet (3.6 m) of shale in outcrops less than a mile (1.6 km) to the east across the Bighorn River (see Section 6 of Fig. 4), and correlate them with Unit IV.

A section measured approximately 7 miles (11.2 km) west of Thermopolis at Rattlesnake Gulch and another 12 miles (19.2 km) northwest of Thermopolis at the west end of Thermopolis Anticline appear to corroborate the erosion surface interpretation presented above. In both sections, and in nearly all outcrops west of Thermopolis, polished pebbles and chalcedony concretions are common in the nearly 100 feet (30 m) of brightly colored, variegated claystone beneath the "rusty series", but the former are restricted to the upper 50 to 60 feet (15 to 18 m), the latter to the lower 20 or 35 feet (6 to 10.5 m). No intervening sandstone (Unit VI) is present at either of these two sites (Sections 3 and 4 of Fig. 4), or at most other exposures west of Thermopolis. The presence of Unit V here seems to be correlated with the absence of Unit VI—just the reverse relationship that is preserved immediately north of Thermopolis only a dozen miles (18 km) or less to the east.

All exposures in the Thermopolis area feature a prominent, although not always resistant, light gray-green or buff to brilliant white sandstone ranging up to 150 feet (45 m) in thickness in the lower part of the nonmarine sequence. A similar facies outcrops at several sites in the Hyattville-Tensleep, Cloverly-Shell Creek and Cody areas. Unit II of our classification was established on the distinctive character of this lower sandstone in the Thermopolis area.

For a summary of previous stratigraphic interpretations in the Thermopolis area compared with designations used in this report, see Chart 3.

Only one minor fossil vertebrate site (YPM 66-2) was discovered in the Thermopolis area, possibly because exposures in the region are not as clean or as extensive as those to the north. Locality 66-2 lies approximately 5 feet (1.5 m) above a resistant sandstone lens in a reddish, variegated claystone (Unit VII) 52 feet (15.8 m) below the lowest sandstone strata of Unit VIII. The locality is 9 miles (14.4 km) northwest of Thermopolis on the north limb of the Thermopolis Anticline, about 200 yards (180 m) east of the point where Coal Draw cuts through the Cloverly hogback (Locality Map A).

CODY AREA. The Cody area encompasses all of the Morrison-Cloverly outcrops along the western margin of the Bighorn Basin from south and west of Cody northward to Clark Fork of the Yellowstone River. Exposures comparable to those along the eastern side of the Basin do not occur in this area, except in the Shoshone River Canyon and along the east limb of Horse Center Anticline south of Cody.

Fisher (1906) was the first to consider the Mesozoic section along the western margin of the Bighorn Basin. In a very brief account of exposures south of Cody (p. 27) he noted a 50 foot (15 m) thick, basal, coarse-grained, pebbly sandstone overlain by softer, gray sandstone of undetermined thickness, in turn overlain by highly colored clay, succeeded by the "top [Cloverly] sandstone member" and a rust-colored sandstone. The entire sequence was referred by him to the Cloverly Formation (Chart 4). This description corresponds to exposures approximately one mile (1.6 km) south of Cody (Plate 7:A) that were prospected and measured by the author (Section 1 of Fig. 4). In my opinion, Fisher's "basal Cloverly sandstone" does not correspond with the basal sandstone in the type Cloverly area. Lithologically it is more similar to the lowest thick sandstone (Unit II) in the southern part of the Bighorn Basin, but more important, chalcedony concretions are extremely abundant in the overlying 230 feet (70 m) of variegated claystone, whereas they are completely lacking below. Thus, his pebbly "basal" sandstone may represent either Unit IV or II, but not Unit VI. Overlying this chalcedony-rich claystone is an 8 foot (2.4 m) thick, tan to light-brown, nonconglomeratic sandstone that may or may not represent Unit VI. This is overlain by 80 or more feet (24 m) of brightly colored, variegated claystone containing frequent polished pebbles but no chalcedony concretions. I believe this corresponds to the middle claystone member of Darton's Cloverly and have accordingly labeled it Unit VII. The Cloverly Formation (*sensu* Darton) on the west side of the Bighorn Basin appears to have thicknesses comparable to those on the east side, 50 to 100 feet (15 to 30 m) thick (Sections 1 and 2 of Fig. 4) rather than 300 feet (91 m) or more as listed by Fisher and others.

Fisher did not give a specific section for the Morrison Formation in this area, simply remarking that it consisted of about 150 feet (45 m) of alternating gray, fine-grained sandstone and dark-gray sandy "shale". This approximates the lower part of the nonmarine section as it is exposed in Horse Center Anticline, which I have designated Unit I in this report.

Hewett (1914) interpreted the Morrison-Cloverly section along the Shoshone River at Cody quite differently, restricting the Cloverly to the predominantly sandstone portion of the "rusty series" and expanding the Morrison to include all the underlying nonmarine sediments. Unit VIII of the present classification corresponds to the lower sandstone part of Hewett's Cloverly Formation, all other Units (I to VII) representing facies of his Morrison Formation (Chart 4). In discussing this section, Hewett comments (p. 94): "As no fossils other than saurian bones from the middle portion have been found in either this formation [Morrison] or the overlying 'Cloverly,' the upper limit is taken to be the base of the sandstone overlying the uppermost maroon clay."

He further noted the absence of a basal conglomerate corresponding to that described by Darton as marking the upper limit of the Morrison Formation. However, Fisher (1906), Lee (1927) and I observed a pebbly sandstone situated approximately 300 feet (91 m) below the lowermost massive sandstone of the "rusty beds". As noted above, I have interpreted this as Unit II and not corresponding to the basal Cloverly sandstone of Darton. This interpretation cannot be verified by walking out exposures, but it appears to be substantiated by the abundant presence of chalcedony concretions in the overlying 230 feet (70 m) of variegated claystone.

Lee (1927: p. 64–65), challenged Hewett's interpretation and limited the Morrison Formation to the lower 240 feet (73 m) of nonmarine beds, correlating a 25 foot (7.6 m) thick, massive and locally conglomeratic sandstone at this level with the basal sandstone of Darton's Cloverly. According to Lee, this is overlain by 260 to 315 feet (79 to 96 m) of variegated, brightly colored claystones containing dinosaur bones, petrified wood and polished "gastroliths". Lee's section was measured approximately one mile (1.6 km) south of the site of our measured Section 1. Here his basal sandstone is much thinner than at our Section 1, but it can be traced to Unit II of Section 1. Thus Lee's subdivision of the nonmarine sequence is identical with that of Fisher, with the Cloverly Formation consisting of Units II, V, VI?, VII and VIII and the Morrison being limited to Unit I (Chart 4).

Johnson (1934: p. 820) concluded that no reliable criterion exists for differentiating the Morrison and Cloverly Formation, noting that the combined formations may be described in three subunits: 110 feet (31.5 m) of buff, thin-bedded to massive sandstone (Unit VIII plus the "rusty series"), 440 feet (134 m) of varicolored clay with many sandstone lenses (Units VII, VI?, V and II), and 180 feet (55 m) of green sandy shale (Unit I). This condensed description apparently was based on the sections exposed in the Shoshone River Canyon at Cody.

Pierce and Andrews (1940: p. 117), in describing the geology south of Cody, "follow the usage of Hewett and place in the Morrison formation the lenticular conglomerate or grit beds and overlying purple and lilac colored shales that have previously been included [by Fisher and Lee] in the lower part of the Cloverly." Of the two "Cloverly" sections presented by them, however, one clearly does not conform to this decision. In Sec. 19, T.52 N., R.101 W. they recorded 118 feet (36 m) of gray, buff and brown sandstone and shale, ripple-marked and iron-stained, which they labeled as Cloverly Formation. This actually is the "rusty series" of other workers, including an equivalent of the Greybull sandstone at the base (Unit VIII). A second section recorded in Sec. 23, T.52 N., R.102 W., less than 3 miles (4.8 km) away on the opposite (west) limb of Horse Center Anticline, lists 192 feet (58.5 m) of Cloverly, which includes more than 60 feet (18 m) of red and gray "shale" underlain by cross-bedded sandstone and conglomerate. From personal observations in this vicinity, I have concluded that the lowest sandstone recorded in the first section equals Unit VIII and that of the second section corresponds to Unit VI (with the red and gray "shale" representing Unit VII). The top 85 feet (26 m) of the latter section corresponds to Unit VIII plus 70 feet (21 m) or more of overlying "rusty series".

Reporting on the Morrison Formation in the vicinity of their second Cloverly section, Pierce and Andrews included 388 feet (114 m) in the Morrison, the upper 70 feet (21 m) of which they describe as variegated "shale" with nodular, siliceous limestone concretions, underlain by 24 feet (7.3 m) of conglomeratic sands. These two facies (and the underlying 68 feet [20.7 m] of claystone) are placed in Unit V. Beneath these they noted an 85 foot (26 m) sandstone and 141 feet (43 m) of "shale" and shaly sandstones that correspond to Units II and I of our measured Section 1. Thus, in their section on the west limb of Horse Center Anticline, Pierce and Andrews separated Morrison from Cloverly at the top of a chalcedony-concretion-bearing claystone (Unit V) and below a conglomeratic sandstone (probably Unit VI), but on the east limb they placed the boundary at the top of the nonmarine section (between Units VII and VIII) (Chart 4). Pierce and Andrews noted (p. 115) the abundance of both chalcedony concretions and "gastroliths" in the upper part of the Morrison (their inconsistent application of the terms Morrison and Cloverly destroys any meaning this might have), but they did not say whether these occur together or not. Our own observations in these locales established that the former occur below the "gastroliths" and at many places a cross-bedded, sometimes pebbly sandstone occurs between the two zones, as has been observed at many other localities in the Bighorn Basin area. Pierce and Andrews' sections are duplicated in Chart 4, together with those of Fisher, Lee, Hewett and Johnson and are compared with the classification used in this report.

Although fragmentary fossil bone was encountered at several levels, chiefly within Unit V, no significant fossil vertebrate localities were discovered in the Cody area.

CROOKED CREEK–GYPSUM CREEK–WARREN AREA. This region, which includes that part of Big Horn County, Wyoming, that lies north of the Shoshone River and adjacent areas of southernmost Carbon County, Montana, proved to be one of the most productive regions discovered during the course of this investigation. Large collections of fossil vertebrates were made from a series of sites along the northwest-southeast-trending Cloverly hogback, particularly in T.58 N., R.95 W. (Locality Map H) approximately 8 miles (12.8 km) north of the Shoshone River and 10 miles (16.0 km) northeast of Lovell, Wyoming.

The first stratigraphic report to consider the Mesozoic section of this area in any detail is that of Washburne (1909). On page 168 of that report, Washburne described the Cloverly section at Gypsum Creek as follows:

> At the base of the Cloverly formation in its typical development on Gypsum Creek, north of Lovell, Wyoming, there is 40 to 50 feet of massive sandstone, locally containing shale partings and a thin coal bed. . . . Overlying this sandstone are 100 to 150 feet of bright variegated clays and soft sandstones, with concretions of limestone and chert. The top member of the formation is a massive gray sandstone about 70 feet thick overlain by 15 feet of dark purplish shale.

Fisher (1908: p. 85), attempting to correlate this same Gypsum Creek section and one near Thermopolis with the much thicker and quite different section of the Kootenai Formation near Great Falls, Montana, similarly recorded the basal sand of the Cloverly Formation at approximately 50 feet (15 m) thick, overlain by 40 feet (12 m) of chert pebble sandstone, which in turn was overlain by 132 feet (40 m) predominantly "shale", the upper part of which contained limestone and chert (chalcedony?) concretions. Overlying this he noted a 70 foot (21.3 m) thick chert pebble sandstone succeeded by 15 feet (4.5 m) of dark-purple "shale". The similarity between Washburne's and Fisher's section is obvious, the most conspicuous difference being the absence of a chert pebble sandstone immediately above the "basal sandstone", as described by Fisher. The local absence of conglomeratic facies associated with this sandstone in the Gypsum Creek area was substantiated by our observations (Section 21 of Fig. 4 and Appendix A at the end of this report). The above Gypsum Creek sections have been located approximately and measured by the author, the sequence having been traced to this locality from the type Cloverly area. The "basal Cloverly sandstone" of Washburne and Fisher (with the overlying conglomerate [= Pryor Conglomerate]) corresponds to Unit IV, the overlying 100 to 150 feet (30 to 45 m) of concretionary clays and sands to Unit V, the 70 foot (21 m) gray chert pebble sandstone to Unit VI and the 15 foot (4.5 m) thick, purple "shale" to Unit VII (Chart 5).

It should be pointed out that this Gypsum Creek section is not typical for the area. A more typical section may be found in the hogbacks between the Crooked Creek and Dryhead roads. Here the lower pebbly sandstone (Unit IV) ranges from 10 to 30 feet (3.0 to 9.1 m) in thickness, with 25 feet (7.6 m) being an approximate average. The overlying low-slope-forming, chalcedony-rich claystone (Unit V) totals approximately 130 feet (39.6 m), and the sometimes pebbly sandstone (Unit VI) above averages about 20 feet (6.1 m) (Section 20 of Fig. 4). The cliff-forming, brightly colored, purplish claystone (Unit VII) ranges from 15 to 70 feet (4.5 to 21.3 m). Similar values were obtained to the south and northwest. Both Fisher and Washburne adopted a

Morrison-Cloverly boundary in this area well below that designated by Darton (1906: p. 52), placing it between Units III and IV rather than between Units V and VI (Chart 5). Again, the chalcedony-rich claystone unit provides the most reliable traceable evidence permitting correlation between the type Cloverly area and the Crooked Creek exposures.

Ziegler's (1917) report on the Byron oil and gas field, although dealing with subsurface stratigraphy at a point some 14 miles (22.4 km) southwest of the Crooked Creek exposures, requires mention here because it adopts a usage quite different from that of Fisher and Washburne. Ziegler, following Hewett's (1914) lead in the Cody area, saw no good reason for dividing the variegated claystone sequence and placed the base of the Cloverly Formation at the base of the massive sandstone overlying the highest variegated clays (Hintze's Greybull sandstone or Unit VIII of this report). He argued (p. 187) that "since climatic and physical conditions have apparently been constant during the entire time of deposition of these clays . . .", it is more logical to include all variegated clays in the Morrison Formation. There is considerable merit in Ziegler's conclusion, but not for the reasons quoted, which are purely hypothetical. In fact, Moberly (1960) has shown that environmental changes did occur between accumulation of the Morrison (Units I to III) and the Cloverly (Units IV to VII) Formations.

Lee (1927: Pl. 2 and p. 63) presented a very brief description of the Morrison-Cloverly section 4 miles (6.4 km) north of Kane, Wyoming (probably at the prominent plunging hogback southeast of Sykes Mountain, about 7 miles [11.2 km] southeast of the Crooked Creek quarry sites). Lee recorded 290 feet (64 m) of Morrison (without description), 50 feet (15 m) of coarse-grained, massive, cross-bedded, basal Cloverly sandstone (which I have identified as Unit IV), approximately 150 feet (45 m) of red, sandy "shale" constituting the middle Cloverly member (Units V, VI and VII), and 75 feet (22.5 m) of upper Cloverly or Greybull sandstone (Unit VIII).

The most recent study in this area is that of Moberly (1960), referred to earlier. Moberly's redefined Cloverly Formation includes the Little Sheep Mudstone Member, based on excellent exposures 4 miles (6.4 km) south of Kane (p. 1145), and the Himes Member based on exposures along the west limb of Little Sheep Anticline between Himes and Lovell, Wyoming (p. 1148). Moberly also proposed the overlying "rusty beds" (including the Greybull sandstone of Hintze and others) as the Sykes Mountain Formation, based on exposures between Gypsum and Crooked Creeks (NE ¼ Sec. 25, T.58 N., R.96 W.). Detailed stratigraphic sections of these units are presented here (Sections 18, 19, 20 and 21 of Fig. 4). During the course of tracing this sequence from the type Cloverly area, we established that Moberly's Little Sheep Mudstone Member equals Unit V, the Himes Member equals Units VI and VII and the lower sandstones of his Sykes Mountain Formation (at least in part) equal Unit VIII. The coarse chert pebble sandstone or conglomerate cited by Moberly at the base of his Little Sheep Member of the Cloverly and identified by him as the Pryor Conglomerate is here equated with our Unit IV.

For a summary of previous terminology applications at specific localities, see Chart 5, and the comparison on pages 12-13.

During the 1962 and 1963 field seasons a total of 33 fossil vertebrate sites were discovered in this area, principally along the east slope of the Cloverly hogback immediately east of Crooked Creek (Plate 4). In addition, the site of A. Silberling's 1949 collection for Princeton University (Locality PU 49-1) was located through the help of Mr. Lloyd Tillett. Extensive collections were made from ten of these sites (Locality Map H). Localities YPM 62-14, 63-22, and PU 49-1 lie within the upper 40 feet (12 m) of Unit V, 20, 2 and 35 to 40 feet (6.0, 0.6, and 10.5 to 12 m) respectively, below the base of Unit VI. Localities YPM 63-16 and 63-32 are situated just below the top of Unit VI (1 to 3 feet [0.3 to .09 m]). All other sites lie within the lower 10 feet (3.0 m) of Unit VII.

BRIDGER-WESTERN PRYOR MOUNTAIN AREA. Included here is the eastern part of Carbon County, Montana, situated between the eastern county boundary and the valley of Clark Fork of the Yellowstone River. The Morrison-Cloverly outcrop belt extends from northeast of Warren, along the west flank of the Pryor Mountains to Bluewater Creek and then eastward to the north slope of West Pryor Mountain. Within the area 41 sites were discovered that produced large collections of fossil vertebrates (Locality Maps I, J, K, L, M, N and O and the Locality Register at the end of this report).

In 1917, C. J. Hares made an informal report to the Geological Society of Washington, D.C. on "Gastroliths in the Cloverly formation". Although not intended as a stratigraphic presentation, the publication of his remarks constituted the first published reference to the Pryor conglomerate. He stated (1917: p. 429): "These gastroliths occur in the shale portion of the Cloverly between the Pryor conglomerate member at the base and the greybull sandstone member." Although black chert pebbles occur locally and infrequently in the sandstone here labeled Unit VI, and despite the presence of conglomeratic sandstones at various levels, the Pryor Conglomerate is sufficiently distinct that there is little disagreement over its identity. On the other hand, there is considerable difference of opinion as to whether the Pryor Conglomerate is, or should be, considered part of the Cloverly Formation or of the Morrison. This first arises in Hares' comments quoted above, wherein he identifies the Pryor Conglomerate as the basal member of the Cloverly. He did not, nor has anyone else to date, establish the equivalency of the Pryor Conglomerate and Darton's basal conglomeratic sandstone. Nor did he suggest a redefinition of the Cloverly Formation. Hares assumed, and others have followed the same assumption, that these were one and the same unit. Consequently, the Pryor Conglomerate is often cited as the basal member of the Cloverly Formation. The most recent instance is the report by Moberly (1960), but Moberly clearly states that he is redefining the Cloverly Formation to include the black chert pebble conglomerate commonly identified as the Pryor Conglomerate. Unfortunately, Moberly never explicitly states that the Pryor Conglomerate and Darton's basal Cloverly sandstone are the same or different units, although he indicated the latter in his representation of Darton's stratigraphic section at the type Cloverly area (Fig. 2). However, other sections of Darton's (those south of Tensleep, at Hyattville, west of Tensleep, at Sheldon's ranch and west of Shell) reproduced in this same figure indicate that Darton selected a basal sandstone at the level of the Pryor Conglomerate in four of his sections—the exceptions being the type Cloverly section and the one at Sheldon's ranch (Shell Creek Dome). However, this is only Moberly's *interpretation* of how Darton subdivided the sections at these localities. Personal examination of the outcrops in question has led me to conclude that Moberly erred in his interpretation of Darton's sections at two of the sites. The basal Cloverly sandstone selected by

Darton south of Tensleep and west of Tensleep, as well as at Shell Creek Dome and at the type section, is definitely the upper sandstone (Unit VI) that overlies the chalcedony concretion-bearing claystone. Only at the exposures west of Shell and immediately south of Hyattville did Darton refer to a lower sandstone (perhaps at the level of the Pryor Conglomerate) as the basal Cloverly sandstone. At both of these latter sites, the strata described by Darton *underlie* the chalcedony-rich claystone (Unit V), and the upper sandstone (Unit VI) is absent or very thin. See Charts 1 and 2 for a comparison of Darton's sections with the classification used here.

Bauer and Robinson (1923) in their "Comparative stratigraphy in Montana" adopted Darton's Cloverly section and his correlations with the Dakota, Fuson and Lakota Formations of the Black Hills region. They further stated that (p. 172): "the shale member below the upper sandstone ['rusty series', Greybull sandstone, or Unit VIII of this report] in the Crow Reservation is the equivalent of the upper Kootenai of northern Montana and the thick conglomeratic sandstone below it is the equivalent of the thick sandstone of the Kootenai of the central and northern part of the state. . . ." They listed a thickness of 313 feet (95 m) for the variegated "shale" between the upper and lower sandstones of their "Cloverly" on the west side of the Pryor Mountains (no precise location is given), and note the "basal sandstone" is conglomeratic around the north end of the Bighorn Mountains where its thickness ranges from 58 to 130 feet (17.7 to 39.6 m). Their Cloverly Formation thus totals 371 to 443 feet (112.8 to 135 m). Discussing the Morrison Formation (p. 173–174), they gave a thickness of 294 feet (89.7 m) in the "Pryor-Beartooth Mountain" area. No comment was made as to whether these Cloverly-Morrison thicknesses were measured anywhere near each other, and the supposition here is that they were not. The maximum thickness obtained by us for the entire nonmarine sequence in this area is 512 feet (156 m) at Bluewater Creek (Section 24 of Fig. 4), or more than 150 feet (45 m) less than the minimum total thickness cited by Bauer and Robinson.

It is unfortunate that no precise location was given by Bauer and Robinson for their data, because without this information precise correlation with our observations cannot be made. However, throughout this area there is only one persistent and distinctive black chert pebble conglomerate within the nonmarine sequence. Accordingly, this must represent their basal Cloverly facies. It equals Unit IV of our classification and has been traced between this area and more southerly exposures where it clearly is not Darton's basal Cloverly member. Overlying this conglomerate (the Pryor Conglomerate) we found variegated gray, purple and bluish claystone, rich in bentonite and chalcedony concretions, ranging from 60 to 112 feet (18 to 34 m) thick, that is traceable to the nearly identical Unit V in the type Cloverly area. Above this claystone we found a variable, soft, yellow to brown sandstone, sometimes containing occasional black or gray chert pebbles, ranging from 3 to nearly 60 feet (0.9 to 18 m) in thickness. I believe this corresponds to Darton's basal Cloverly sandstone and accordingly have labeled it Unit VI. Overlying this is 20 to 90 feet (6 to 27 m) of brightly colored, variegated, polished pebble-bearing claystone (Unit VII) capped by a variable thickness of tan to rusty-brown, thinly or massively bedded sandstone (Unit VIII). Thus Bauer and Robinson's Cloverly Formation appears to correspond to Units IV through VIII of our classification (Chart 6).

One of the early attempts to correlate the Morrison-Cloverly section of the Pryor Mountain region with sections outside the Bighorn Basin is that of W. T. Lee (1927).

Lee compared 13 sections scattered between Thermopolis and Pryor with other sections at Lewistown and near the Big Snowy Mountains of central Montana and a section at Bellvue, Colorado. Included is a section at Red Dome (p. 65) near Bridger, Montana, based on data supplied by R. S. Knappen. This latter section agrees with one of our measured sections (22 of Fig. 4) and with the general description of the Cloverly Formation given by Bauer and Robinson (1923) and Knappen and Moulton (1930). Again, it is my opinion, based on extensive examination of the exposures in the Red Dome and adjacent areas, that the basal conglomerate of Lee's Bridger section is the same as that of Bauer and Robinson and corresponds to Unit IV of the present study and therefore does not correspond to the basal sandstone (Unit VI) described by Darton (1906). Thus Lee's Cloverly Formation in this area includes our Units IV, V, VI, VII and VIII.

Knappen and Moulton (1930) noted a 589 foot (180 m) thickness for the nonmarine sequence in Carbon County, but they did not include a measured section (a slightly thinner measured section is included from near Pryor 20 miles (32 km) to the northeast). Knappen and Moulton divided this nonmarine section at the base of a black chert pebble conglomerate (not identified by them as the Pryor Conglomerate) that almost certainly is the same one selected by Bauer and Robinson and by Lee, and labeled here as Unit IV. Their overlying Cloverly clay member (90 to 240 feet [27.5 to 73 m]) includes our units V, VI? and VII and their Greybull sandstone member corresponds to Unit VIII (see Chart 6).

Of particular interest is the following comment by Knappen and Moulton (1930: p. 25): "A very lenticular, coarse, soft brown sandstone is present at many places about 30 feet below the top of the bright colored, variegated clay. This sandstone ranges from a feather edge to 60 feet in distances of 1000 feet." The authors do not record whether the sandstone contains black chert pebbles, but personal observations have established that a sandstone matching their description commonly present at about this level is pebbly locally and does contain infrequent dark chert pebbles. The unit is discontinuous, but it always lies between the chalcedony-rich claystone and the overlying polished pebble-bearing claystone. It is my conclusion that this sandstone probably represents Unit VI and thus is equivalent to the basal sand of Darton's type Cloverly. In the absence of detailed measured sections by Knappen and Moulton these correlations cannot be confirmed, but the following observations by them do seem to support my interpretation. They describe (1930: p. 24–25) the lithologies above their conglomeratic basal member of the Cloverly as "bright red, green, purple, yellow and dull black clays. . . . Much of the clay swells like bentonite when wet and forms gumbo mud which is porous and collapses under pressure after drying." They further note the amazing abundance of polished, well-rounded stones which "some geologists hold are gastroliths". Unfortunately, they do not present any details on the stratigraphic distribution of these polished stones within the 90 to 240 feet (27.5 to 75 m) of clays above their basal conglomerate, or on the distribution of the collapsible gumbo muds. Our analysis at the same locale found the so-called gastroliths restricted (*in situ*) to the upper cliff-forming claystones (which here are reddish to purplish) and the collapsible gumbo clays (which usually are drab gray and pale green) limited to the lower part of the section and always below the soft, brown sandstone described above. These characteristics are consistent with those observed in more southerly outcrops within the study area and seem to confirm the persistence and distinctiveness of

Units V and VII. Knappen and Moulton's basal Cloverly member thus would seem to correspond to our Unit IV. Like that of their predecessors, their Cloverly Formation clearly appears to be an expansion of that formation over Darton's 1906 definition.

Wilson (1936: p. 1167) recorded a composite section between Bowler (now an abandoned town near the southwest boundary corner between Yellowstone and Carbon Counties) and Dry Creek (South Fork of Bridger Creek?) in which the "Cloverly" claystone is 150 feet (45 m) thick and the brown and yellow, black chert pebble-bearing sandstone beneath is 50 feet (15 m) in thickness. Wilson lists the total nonmarine section here (excluding the sandstones of the "rusty series") at about 400 feet (122 m) thick. These values are very close to values we obtained at Red Dome (Section 22 of Fig. 4) and indicate that Wilson subdivided the Morrison and Cloverly Formations at the same horizon as his predecessors (the base of Unit IV), but Wilson's data are not sufficiently detailed to permit accurate comparison with earlier works or with our data.

Lammers (1939) discussed the origin and correlation of the "Cloverly conglomerate", but in the absence of detailed measured sections and the exact stratigraphic level of his "Cloverly conglomerate" at any particular locality, it is impossible to ascertain which of the coarse clastic units in this region he was referring to, or to make meaningful comparison with the sections recorded here. On the basis of his description, it is most probable that his "Cloverly conglomerate" is synonymous with Pryor Conglomerate (*sensu* Hares), in which case Lammers' Cloverly Group includes our Units IV through VIII. Lammers (p. 131–132) correlated the "Cloverly conglomerate" of this area with the coarse-grained sandstone overlying the Kootenai coal beds in central Montana and with the basal conglomerate of the Blairmore Formation in Alberta.

Gardner et al. (1945: p. 79–80) published a measured section on Five Mile Creek (NE ¼ Sec. 35 and SW ¼ Sec. 36, T.5 S., R.24 E. and N ½ Sec. 1, T.6 S., R.24 E.) about 5 miles (8 km) east of our measured Section 24 and in the vicinity of Locality YPM 64-65. Their section has been duplicated in Chart 6. From our observations in the immediate area, rocks that they assigned to the Kootenai Formation include Units IV, V and VI. They omit any mention of the upper variegated claystone (Unit VII) although it is prominently exposed locally in the area. Their basal conglomeratic sandstone is the Pryor Conglomerate of other authors (Unit IV).

The Morrison Formation as recognized by Gardner et al. includes our Units III and possibly I, totaling 125 feet (38 m) of sandstones and claystones. A 10 foot (3 m) resistant sandstone near the middle of their Morrison section may represent Unit II of more southerly exposures, but this cannot be verified. Lateral variations in thickness and changes in grain size indicate it probably represents a local channel deposit.

Moberly (1960) provides no measured sections in the area under consideration here, but in a geologic map of the Red Dome area (Moberly, Fig. 7) he recognized the same subunits that he proposed for the nonmarine sequence exposed in Bighorn County, Wyoming. Presumably, his subunits in the Red Dome area can therefore be equated with our classification exactly as is listed on pages 12-13 of this report.

The stratigraphic interpretations of most of these workers, compared with terminology used here, is summarized in Chart 6.

A total of 41 fossil sites was discovered in the Bridger-Pryor Mountain area during the 1964 field season. Each site was explored and evaluated, and extensive quarrying and collecting were carried out at 16 of the sites. The sites are pinpointed on

Locality Maps I through O. The fossil-bearing horizon at each locality (with the exception of YPM 64-54) lies in or above Unit VI; the precise level of each is recorded in the Locality Register (Appendix B) at the end of this report.

PRYOR–BEAUVAIS CREEK AREA. This area includes the northwestern part of Big Horn County and the southernmost part of Yellowstone County, Montana, and lies entirely within that part of the Crow Indian Reservation west of the Bighorn River. The region is characterized by broad, nearly flat-topped plateaus or "benches" bounded by 100 to 300 foot (30 to 90 m) high scarps, low to moderately high cuestas and broad stream valleys. The underlying strata are nearly horizontal in much of the area with dips increasing to 15 or 25° approaching the Bighorn and Pryor uplifts. Exposures of the Morrison-Cloverly sequence occur in erosional scarps bounding the plateaus and on the back slopes of cuestas. The outcrop belt follows the southern limit of the high plateaus north of the town of Pryor and along the valley of Pryor Creek in the western sector, then roughly parallels the course of Beauvais Creek eastward to its junction with Horse Coulee, from which point it swings southeastward toward Grapevine Creek and the Yellowtail Dam site on the Bighorn River (Fig. 2).

The earliest reference to the Morrison-Cloverly section in the region is that of Bauer and Robinson (1923). They presented (p. 172) a thickness of 105 to 151 feet (32 to 45 m) for the variegated "shale" between the upper and lower sandstones of their "Cloverly" on the east side of the Pryor Mountains (presumably somewhere in the vicinity of Beauvais Creek) and the conglomeratic sandstone at its base as 58 to 130 feet (17.7 to 39.6 m) at the north end of the Bighorn Mountains. No precise locality was given, however, and we failed to find any exposures in which the conglomeratic sandstone exceeded (or even approached) their minimum value. Bauer and Robinson correlated the "shale" member (Units V to VII?) below the upper sandstone with the Upper Kootenai of northern Montana and the thick conglomeratic sandstone (Unit IV?) beneath with the prominent, thick sandstone of the Kootenai in central and northern Montana. The Morrison Formation, according to these authors, varies from 100 to 150 feet (30 to 45 m) in thickness and consists chiefly of hard, greenish-gray "shale" with some pink and purple "shales", and gray-green, white and yellow sandstones. Because no measured sections or precise localities are given, it was impossible for us to make any meaningful comparisons with our data. However, their thicknesses cited above for the Cloverly and Morrison Formations are thicker and thinner, respectively, than those which we recorded in this area. I believe that the section assigned by Bauer and Robinson to the Cloverly Formation includes Units IV through VII (they gave no thickness for the upper sandstone—the equivalent of our Unit VIII—but they apparently considered this as the upper member of their Cloverly Formation), and the 100 to 150 feet (30 to 45 m) assigned by them to the Morrison Formation includes only Units I through III.

W. T. Lee (1927) published a geologic section (Pl. 2), measured by W. T. Thom, Jr., at exposures near Pryor, Montana, which consisted of 20 feet (6 m) of basal conglomerate, 106 feet (36 m) of colored "shales" and 20 feet (6 m) of sandstone at the top, the entire sequence being assigned to the Cloverly Formation. This approximates the section observed by us in the vicinity of Pryor, and it appears that these three elements are the same as those that we have labeled VI, VII and VIII. However, in view of the nature of the exposures at this locale, I suspect that Lee selected the most conspicuous conglomerate as his basal conglomerate. A massive and thick conglomerate is prominently exposed west and south of Pryor and, although exposures do not permit determination of its position relative to the chalcedony-concretion-bearing claystone, it is my opinion that this is the Pryor Conglomerate, and I have correlated it with Unit IV (see Section 25 of Fig. 4). Hence, it is quite possible that Lee's Cloverly in this vicinity includes Units IV through VIII.

The most extensive study of the geology in the Crow Indian Reservation is that of Thom et al. (1935). They note several measured sections of the Morrison-Cloverly complex. One of these (p. 45), located in SW ¼ Sec. 13, T.5 S., R.25 E. approximately 4 miles (6.4 km) southwest of Pryor, identified a Cloverly section that is identical with that reported by Lee and agrees with our Units VI, VII and VIII as recorded west of Pryor (see Section 25 of Fig. 4). As noted above, however, their basal unit may correspond to our Unit IV. A second section (p. 45) (located in Sec. 22, T.9 S., R.34 E., south of the Little Bighorn River on the east side of the Bighorn Mountains) is far removed from the area considered here and was not checked during the present investigation. At that site, they list 185 feet (56.5 m) of Cloverly, the upper sandstone totaling 12 feet (3.6 m) and the basal sandstone 24 feet (7.2 m). This section may include Units IV and V as well as one or more of the overlying units for they note the "great numbers of concretions formed of chalcedony and calcite" occuring in a soft, light gray "shale" 64 feet (19.5 m) above the "lower sandstone" *and* that "gastroliths are also found at this horizon". Except for surface associations, the latter is contrary to our findings elsewhere. As I have noted before, in the process of quarrying at more than 50 sites in Units VI and VIII, polished pebbles were frequently encountered, but not a single chalcedony, calcite or barite concretion was found. In contrast, such concretions are abundant almost everywhere in Unit V. MacClintock (1957: p. 27 and 36) recorded a similar, non-overlapping distribution of polished pebbles and chalcedony nodules at several localities along the eastern flank of the Bighorn Mountains between Mayoworth and Arminto. The description given by Thom et al. of the above section (pink, red, and purple shale above the chalcedony level and gray shales below) suggests that Unit VI may be absent or very thin at their section site and that what they refer to as the basal sandstone may actually correspond to Unit IV of this report or to some other coarse clastic unit.

In addition to these sections, a number of well logs are cited by Thom et al. from Pryor-Beauvais Creek area. It is apparent that subsurface placement of formation boundaries in at least some instances is not consistent with the usual placement of the same boundaries in nearby surface exposures. One of their logs is cited here because it happens to have a critical location in the Beauvais Creek Valley in the immediate vicinity of a number of our fossil vertebrate localities where large collections and detailed stratigraphic sections were obtained (see Locality Map U and Sections 27 and 28 of Fig. 4). The well ("56" Petroleum Corporation's Well 1, Beauvais Creek Uplift) raises a problem that we could not resolve: that is, either the location given (SW ¼, NE ¼ Sec. 28, T.4 S., R.29 E.) is in error or the log has been grossly misinterpreted. According to the log, the top strata penetrated by this well are identified as Cloverly (Thom et al., 1935: p. 110), but the location given places the well in the valley bottom between Beauvais and Buster Creeks some 150 to 200 feet (45 m to 60 m) below the "upper sandstone" of the nonmarine sequence that crops out as the capping rim-rock on both sides of the valley. The valley width at this point is between

5,000 and 7,000 feet (1,525 and 2,135 m) and there is no evidence of downwarping or faulting in the immediate area. The exposures on both sides of the valley include Units VI, VII and VIII and locally the upper part of V. Unit VIII ranges from 20 to 50 feet (6 to 15 m) thick, Unit VII from 31 to 80 feet (9.5 to 24.4 m) and Unit VI from 0 to 15 feet (0 to 6 m) (Sections 27 and 28 of Fig. 4). This gives a total maximum thickness of 135 feet (31 m) for the section that I consider to correspond to Darton's Cloverly Formation. The base of Unit VI on both sides of the valley is well above the level of the given well site, yet the log (reproduced below) identifies 228 feet (70 m) of Cloverly in subsurface, overlying 134 feet (40 m) of Morrison. If the well is situated in the Beauvais Creek Valley where indicated (we were not able to locate such a well), some 150 or 200 feet (45 to 60 m) below the top of the nonmarine section, then the Cloverly Formation (as identified in this log) at this point has a thickness close to or exceeding 400 feet (120 m) and the total nonmarine section has a thickness of 514 to 564 feet (160 to 180 m). The maximum thickness found by us in exposures in the Beauvais Creek area was 209 feet (63 m) for the *entire* nonmarine section (Section 27 of Fig. 4) approximately 2 miles (3.2 km) southwest of the listed well site (Sec. 5, T.5 S., R.29 E.) (see Plate 5:B). Thus it appears that the following well log has been identified with the wrong well (which seems unlikely),

"56" Petroleum Corporation's Well no. 1, Beauvais Creek Uplift.
(Thom et al., 1935: p. 110)

	Thickness	Depth
Cloverly Formation		
Sand, water	5	25
Shale, red	20	45
Shell, lime	3	48
Shale, red	22	70
Shale, sand, pink	12	82
Shale, gray	23	105
Shale, blue	10	115
Shale, gray	33	148
Shell, lime	6	154
Sand, light gray, no water	94	248
Morrison Formation		
Lime, pink	40	288
Shale, gray	7	295
Shale, red	5	300
Shale, blue	45	345
Sand, gray	28	373
Shale, gray	9	382
Sundance Formation		
Shell, lime	4	386
Shale, gray	64	450
Shale, sandy, blue	5	455
Sandy, light gray and hard	5	460
Lime	23	483
Shale, blue	181	664
Red beds	22	686
Shell, lime	16	702
Lime	90	792
Chugwater Formation		

the well location is in error, or the formation boundaries have been misplaced. Comparison of surface exposures in the area with the following log has led me to conclude that the last explanation is the most probable.

Of particular interest in the above log is the 94 foot (28.7 m) thick light-gray sand listed at the base of the "Cloverly". A sandstone matching this description occurs near the middle of the Sundance Formation in outcrops 3 to 4 miles (4.8 to 6.4 km) south of Beauvais Creek, but nothing approaching the thickness cited was found in the nonmarine section anywhere near the well site. Another significant fact is that we found shell fragments (*Gryphaea*) on the surface (but not *in situ*) in the lowest exposures in "Cashen pocket" approximately 200 feet (61 m) below Unit VIII (see Plate 6:B), which indicate that the Sundance probably lies very close to the surface at this point only a mile (1.6 km) northeast of the well site and at an elevation close to that listed for the well. On these grounds, it appears quite probable that little if any of the well log given above includes any part of the nonmarine section, and the lithologies listed for both the Cloverly and Morrison Formations are referable to the Sundance Formation.

Richards (1955: p. 41–42), reporting on the geology of the Hardin-Bighorn Canyon area, listed thicknesses for the Morrison Formation of 140 to 280 feet (42.7 to 85.4 m) and for the Cloverly Formation of between 300 and 400 feet (91 and 122 m) in the region south of the Bighorn River along the east side of the Bighorn Mountains. Our investigation did not extend to this area, so no precise comparisons are made in this report. However, Richards included the "rusty series" as the uppermost member of the Cloverly Formation on the basis that it represents the stratigraphic equivalent of the Fall River Sandstone of the Black Hills region and that the overlying Thermopolis Shale corresponds to the Skull Creek Shale of that region. Inclusion of the "rusty series" in the Cloverly Formation follows some earlier interpretations but is at variance with certain recent works and current definition by the United States Geological Survey which consider these as transitional transgressive marine facies closely related genetically to the overlying marine Thermopolis Shale. The variable nature and even absence of the "Greybull" or "upper sandstone" (as a distinctive massive bed) at this level makes it impossible to use this unit as a marking horizon between the Cloverly and the overlying marine shale. However, conspicuous parallel stratification, usually reflected in the highly fissile character of the "rusty series", is in sharp contrast to the obscure bedding of the variegated claystones immediately beneath. This character may serve as a practical criterion for separating the Cloverly Formation from the overlying Sykes Mountain or Thermopolis Formations. Waage (1955, 1958, 1959a, 1959b) has cited the frequent occurrence of siderite spherulites just below the transgressive disconformity separating the Late Jurassic – Early Cretaceous nonmarine and marine sections in Colorado and the Black Hills region; he correlated (1959a: p. 57) this siderite zone with the initial transgression of marine conditions. We occasionally found such spherulites in the upper 2 to 4 feet (0.6 to 1.2 m) of Unit VII or the lower 6 to 8 feet (1.8 to 2.4 m) of Unit VIII.

It is quite possible that this spherulite zone is much more persistent than we found it to be (unweathered siderite spherulites are difficult to recognize), in which case it might serve as a more effective marking horizon in the Bighorn Basin for delimiting the Cloverly and Sykes Mountain or Thermopolis Formations.

For a comparison of previous interpretations and the present classification see Chart 7.

A total of 44 fossil vertebrate localities were discovered in this area during the 1964 field season. Of these, 23 produced important collections. In addition, a number of collections were made by American Museum parties in 1903, 1904, 1931, 1932, 1933, 1938 and 1955 and by the University of Oklahoma in 1940. Some of the American Museum localities, particularly in the Cashen ranch area on Beauvais Creek, were relocated with the help of oblique aerial photographs, prepared by Barnum Brown, that pinpointed a dozen sites (see Plate 6) ; he also recorded the specimens collected at each place. These sites were verified by personal inspection, which showed signs of prior excavation, abundant fresh bone fragments, and "artifacts" left by earlier collectors. Most of the American Museum sites outside of the immediate vicinity of Cashen ranch could be only approximately located, except for two localities (AMNH 31-9 and 31-10) north of Pryor that were relocated with the assistance of Roy Marsh of Pryor, who had aided Barnum Brown in quarry operations at both sites. The two University of Oklahoma sites south of Cashen ranch were relocated approximately through information provided by Dr. Wann Langston of the University of Texas. These localities are recorded on Locality Maps P through X.

The stratigraphic levels of the bone-bearing horizons vary considerably among the localities. Many, but not all, of the American Museum sites have been found to lie within Unit V. The University of Oklahoma sites also occur in the upper part of this Unit. The majority of Yale sites are situated in Unit VII but a few occur in Units V and VI. The precise stratigraphic levels of the fossil horizons of nearly all of these localities are recorded in the Locality Register (Appendix B) at the end of this report.

MIDDLE DOME AREA. Middle Dome is one of three domal structures on the west end of the Shawmut Anticline in Wheatland County, Montana. It lies outside of the principal study area shown in Figure 2 approximately 50 miles (80 km) to the northwest, about 8 to 10 miles (12.8 to 16 km) SSE of Harlowton (Fig. 1). It is included in this report because of collections made in the area, purportedly from the Cloverly Formation, by the American Museum of Natural History in 1933.

Bowen (1919: p. 197–198) described the Middle Dome exposures as having ". . . at the top 50 feet of thin-bedded, fine-grained, platy sandstone of somewhat rusty appearance [Unit VIII?]. . . . Below this sandstone is 45–50 feet of drab to greenish gray shale, which is succeeded by alternate beds of maroon and white shale containing some interbedded sandstone. The lowest member exposed is a coarse gray sandstone that roofs over the centers of middle and west domes of Shawmut anticline." These strata are generally similar to the Morrison-Cloverly sequence to the south, but we were unable to distinguish with certainty most of the units we established in the Bighorn Basin. Bowen's upper sandstone probably represents our Unit VIII and the lower sandstone closely resembles and is presumed to be continuous with the Pryor Conglomerate (Unit IV). The intervening variegated claystones may represent one or more of the expected Units (V, VI and VII). Polished pebbles were found locally, but only as surface features on low-angle slopes in the lower third of the claystone section. Chalcedony concretions are rare and the few that were found could not be traced to a definite stratigraphic horizon. The claystone sequence approaches 150 feet (45 m) in thickness, the upper 20 to 40 feet (6.1 to 12.2 m) being gray-green medium-gray and weathering to yellow or orange brown. The middle part (80 to 100 feet [24 to 30 m]) is brightly variegated, weathering to deep maroon and brick red with pale-lavendar and light-gray zones. The lower 20 to 50 feet (6.1 to 15 m) usually is neutral dark gray, on both fresh and weathered surfaces, and is highly bentonitic. The latter is thought to correspond to our Unit V. The more brightly colored section above probably equals our Unit VII.

Gardner et al. (1945, 1946) published a series of stratigraphic sections from southern and central Montana, but the closest of these is more than 25 miles (40 km) to the north. No detailed attempt was made to correlate the Middle Dome section with any of their sections. However, those authors and most other students working in central Montana place the lower boundary of the Kootenai Formation at the base of a resistant, massive, gray, frequently conglomeratic sandstone. This basal unit has been correlated by most authors with the Pryor Conglomerate on both lithic and stratigraphic grounds. Thus the Kootenai of central Montana probably corresponds to Units IV, V, VI? and VII of the Bighorn Basin.

Our principal objective in extending the investigation to the Middle Dome area was to rediscover the locations and stratigraphic positions of the American Museum localities. Our efforts were largely unsuccessful. Only one site (AMNH 33-1) was relocated and that was possible only because its position had been recorded by Barnum Brown on a photograph (see Plate 7:B). Locality AMNH 33-1 is situated in the upper 10 to 20 feet (3 to 6 m) of the variegated maroon "shale" noted by Bowen, some 100 feet (30 m) above the basal Kootenai sandstone (Unit IV?). This level probably corresponds to the middle or upper part of Unit VII. The site is located on the north rim of Middle Dome approximately 0.25 mile (0.4 km) east of the north-flowing stream that drains the Middle Dome depression.

None of the other American Museum sites at Middle Dome could be found, and several days of prospecting in the area netted only indeterminate bone fragments.

DISCUSSION: PREFERRED TERMINOLOGY

Early in our investigation it became apparent that we faced a major problem—the near impossibility of placing our paleontologic collections within a generally accepted stratigraphic framework. Except for the contact between the Morrison-Cloverly sequence and the underlying marine Sundance Formation, there appeared to be no universally recognized datum to which we could refer our collections. While that contact is perhaps the most reliable, it was of little value for such purposes because few of our collection sites occur near exposures which reveal this datum. Recently, Waage (1955, 1958, 1959a, 1959b) and others have established the regional extent of a transgressive disconformity separating the Upper Jurassic–Lower Cretaceous continental sequence from the overlying marine strata. This datum has been recognized in many parts of the study area, but again, as with the Sundance datum, it is rarely preserved or exposed in the vicinity of our collection sites. Consequently it was necessary to obtain other stratigraphic data in order to establish a framework to which our collections could be referred and that could be related to the stratigraphic data and terminology of previous workers. These data have been presented in the preceding pages.

At this point it is appropriate to ask which—if any—of the various terminological usages that have been applied to the Morrison-Cloverly sequence is preferred? Should we adopt a restricted application of the term Cloverly (*sensu* Darton, 1906), or a more expanded usage (after Moberly, 1960), or should the entire nonmarine sequence be placed in a single formation (as suggested by Hewett, 1914)? I have striven to present the preceding stratigraphic information in a form free of the usual classical labels, but now I must conform to more usual stratigraphic practices. Certainly it would simplify things greatly if the entire nonmarine sequence could be accepted as a single formation, as suggested or implied by several workers. However, the majority of stratigraphers that have considered these strata seem to favor subdivision into two formations. Most recently, Moberly (1960) has cited significant lithic evidence in favor of this position and now our studies show that there is substantial paleontologic evidence to support such subdivision. The question now resolves itself to the matter of placement of the interformational boundary.

Darton did not specify a type section for his Cloverly Formation but he did locate the site of his detailed measured section (1906: p. 52). Consequently, there can be no doubt as to precisely what part of the nonmarine section Darton assigned to his new formation. On the basis of his measured section, we have established that Darton's Cloverly Formation corresponds to Units VI, VII and VIII of the present report. In the years that followed, most geologists failed to recognize the strata specified by Darton, or chose to adopt different definitions. A few of these reports (Hewett, 1914; Johnson, 1934; Moberly, 1960) clearly indicate that their usage constitutes a redefinition of the formations, but most do not, and the supposition here is that the latter reports contain misapplications of Darton's terminology. Whatever the sources of the diverse applications summarized in Figure 3, our efforts have demonstrated to my satisfaction that the Cloverly Formation as defined by Darton is both widespread and recognizable throughout the Bighorn Basin region and thus might well be retained as a valid formation.

To return to Darton's usage, however, would probably add further to the confusion that has plagued work on this part of the stratigraphic column. Whether by intent or through error, a majority of stratigraphic reports dealing with this region have placed the Morrison-Cloverly contact at the base of the Pryor Conglomerate (or a nearly identical conglomerate at approximately the same stratigraphic level). In some reports it is clear that the author erroneously equated the Pryor Conglomerate with Darton's basal sandstone. Prevalent usage would seem not to favor returning to Darton's definition. Most recently, Moberly (1960) has proposed a formal redefinition of the Cloverly Formation within the Bighorn Basin, placing the lower boundary at the base of the Pryor Conglomerate or at the base of the lowest strata which show "evidence of significant additions of volcanic debris". His evidence of volcanic debris (p. 1145) includes "bentonites, partly bentonitic mudstones and claystones, highly siliceous rocks such as cherty siltstones, tuffaceous mudstones and spotted to white cherts, and variegated rocks especially colored shades of pale-red, light to dark-purple, pale-greenish-yellow and neutral gray." Moberly's analysis presents the most detailed evidence so far available and constitutes the best reasons for subdividing this section in the study area. Accordingly, I have followed Moberly's terminology in this report. Units I, II and III are assigned to the Morrison Formation and Units IV, V, VI and VII are included in his redefined Cloverly Formation. The sandstones (Unit VIII) at the top of the nonmarine section (Greybull sandstone of some authors) are included in the transitional series ("rusty beds") which Moberly has formalized as the Sykes Mountain Formation.

A comment regarding the latter unit is in order here, although it is peripheral to the main objectives of this study. For many years there has been a lack of precision as to what has been meant by the term "rusty beds". It is evident, as I have shown in the preceding pages, that Darton included a massive to thin-bedded sandstone at the base of the "rusty series" as the uppermost element of his Cloverly Formation (as defined by him in 1906). Ever since Moberly (1960) formalized the "rusty series", including the lowest sandstone (our Unit VIII), as the Sykes Mountain Formation, a debate has developed as to whether the new terminology should be adopted or whether Darton's inclusion of the "rusty series sandstone" (Greybull sandstone) should be retained. Some favor recognition of the Sykes Mountain as the upper member of the Cloverly Formation as being most consistent with prevalent usage in the literature. Others argue that since this unit (at least in many places) contains the siderite spherulite zone that is judged to mark the transition from terrestrial to marine conditions, it is more logical to separate the Cloverly Formation from the overlying transitional and marine strata at this level—or at the base of the sandstone. Clearly there is merit in both positions.

It is not my intention to evade the problem, but in view of the fact that none of our fossil vertebrate collections were obtained from Unit VIII, and because we did not extend our searches or our sections more than a few feet above the underlying claystone, I feel unqualified to adopt a formal position here. I have not had to concern myself with stratigraphic placement of fossil collections within the Sykes Mountain Formation.

I have listed the Sykes Mountain as a formation in the included columns and referred to it as such in discussions only because it is my impression that this application is less ambiguous than are many of the older terms that have been applied, at least within the area we studied.

3. STRATIGRAPHIC DISTRIBUTION OF FOSSIL VERTEBRATES

Perhaps the most important product of this investigation, aside from the collection of a previously little known and unpublished fauna, is data on the distribution of fossil vertebrates found in the Morrison-Cloverly sequence. Two distinct vertebrate faunas are present, apparently with no overlap. The new fauna appears to be restricted to the Cloverly Formation (*sensu* Moberly), at least within the study area, while a typical Morrison fauna is limited to Units I, II and III.

Our collections were made primarily from Unit VII and secondarily from Units VI and V. No collections were obtained from Unit IV. Excluding the famed Howe Quarry of the American Museum (which produced only Morrison taxa), as far as I know all collections from this sequence made by other institutions were collected from Unit V or above. With the exception of fragmentary crocodilian remains similar to "*Goniopholis*", not one specimen in all these collections is referable to a Morrison taxon. (The status of the genus *Goniopholis* is far from established and it is probable that many specimens have been referred to that genus that should not have been.) Although we did not carry out extensive exploration of Units I, II and III, a number of identifiable specimens (all fragmentary) were found in these lower units during the course of our traverses. All of them were referable to Morrison taxa (*Stegosaurus*, *Camptosaurus*, *Allosaurus* and *Apatosaurus*). If elements of the Cloverly fauna are present in these lower units, we did not recognize them.

The precise level of the Morrison-Cloverly faunal change is difficult to establish because of the rare occurrence of vertebrate remains in all parts of the sequence. The best assessment at present is that the Cloverly fauna is not known below Unit V and the Morrison fauna is unknown above Unit III. The change thus appears to coincide approximately with Unit IV—the Pryor Conglomerate. Unfortunately, identifiable remains have not been found in the Pryor Conglomerate so it is not known whether the faunal change took place before or after accumulation of that Unit. Nevertheless, it is clear that these faunal distributions approximate the revised stratigraphic alignments proposed by Moberly. It seems unlikely, in view of the lithotopic evidence presented by Moberly, that this is due to chance. The stratigraphic distribution of these faunas thus seems to add significant new evidence in support of Moberly's redefined Morrison and Cloverly Formations in the Bighorn Basin area.

The extreme rarity of most vertebrate taxa within the Cloverly Formation makes it difficult to establish actual stratigraphic ranges. Figure 5 summarizes the known stratigraphic distributions of the major Cloverly taxa plotted against a generalized stratigraphic column. These taxa are described in the following section on systematic paleontology. For precise stratigraphic occurrences of individual specimens see the stratigraphic data of the appropriate locality listed in Appendix B.

Unfortunately, only three taxa are represented by large enough samples to provide meaningful stratigraphic ranges. These are *Tenontosaurus tilletti* (gen and sp. nov.), *Sauropelta edwardsi* (gen. and sp. nov.) and *Deinonychus antirrhopus*. *Tenontosaurus* appears to occur at all levels within Units V, VI and VII but is most common in the upper part of V and the lower part of VII. *Sauropelta* also appears to range throughout most of the same three units, but again the most common occurrences are in the upper few feet of Unit V and the lower part of Unit VII. *Deinonychus* is limited to the upper 30 feet (9 m) of Unit V, Unit VI and the lower part of Unit VII. It is most common in the latter. All three taxa appear to be distributed through the sequence without regard to lithology. As might be expected, fossil remains from Unit VI occur as isolated and water-worn elements. The only articulated specimens were found in the finer grained claystones of Units V and VII.

The remainder of the Cloverly fauna is known only from the upper part of Unit V or above. This probably does not represent a true lower limit for these elements of the fauna for several reasons. We expended considerably more effort on the upper part of the sequence (upper half of Unit V, Units VI, and VII) for the simple reason that these strata are more abundantly exposed than are the lower strata. Exploration of the lower part of Unit V, however, was relatively unproductive, and it is my impression that it is much less fossiliferous than the overlying beds. In view of the low occurrence of both *Tenontosaurus* and *Sauropelta*, the two most common taxa, I suspect that many, if not all, of the less common elements of the fauna also range close to the base of Unit V. I regret that we were unable to establish this suspicion as fact, but the effort required would be excessive, for even the fossiliferous levels of Unit VII—our most productive zone—would be considered barren by most standards.

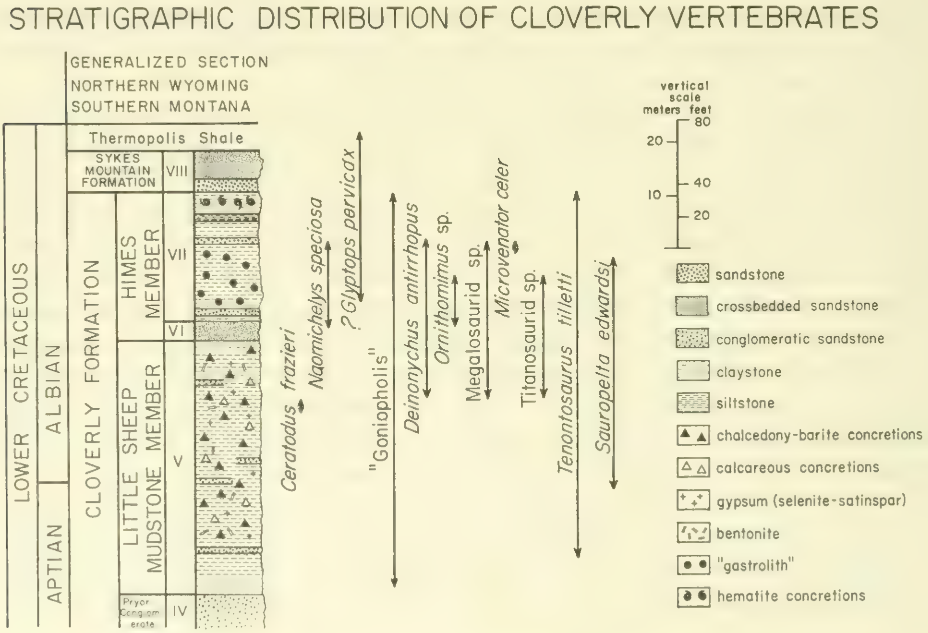

FIG. 5. Stratigraphic distribution of Cloverly vertebrates.

4. SYSTEMATIC PALEONTOLOGY

The extensive collections obtained by American Museum expeditions during the 1930's and Peabody Museum of Natural History expeditions during the 1960's consist of a large number of partial or nearly complete skeletons, isolated teeth and bones, and fragmentary elements. Most of these represent new species of saurischian and ornithischian dinosaurs. Some of the remains, notably of chelonians, crocodilians and sauropods, are known only from fragments or isolated teeth and postcranial bones. The latter are described and illustrated where appropriate, but some are only tentatively referred to a family or other category because existing material is not adequate for more definite assignment. Despite these difficulties, the sauropod material is described in some detail because it appears to represent the most significant sauropod remains from the Lower Cretaceous of the Western Hemisphere and as such is of particular importance.

Class OSTEICHTHYES

Subclass SARCOPTERYGII
Order DIPNOI

Family CERATODONTIDAE Gill, 1872

Ceratodus Agassiz

Ceratodus Agassiz, 1837.

TYPE SPECIES: *Ceratodus latissimus* Agassiz, 1837.

TYPE LOCALITY: Near Bristol, England.

KNOWN DISTRIBUTION: Rhaetic of Europe.

Ceratodus frazieri, new species
Plate 8: B; Plate 9: A

ETYMOLOGY: *Ceratodus frazieri*; named for the Wilford Frazier family of Billings, Montana, to whom I am indebted for much assistance.

TYPE SPECIMEN: YPM 5276, a left mandibular dental plate.

TYPE LOCALITY: Approximately 225 feet (75 m) southeast of Princeton University locality 49-1, NW ¼ Sec. 34, T.58 N., R.75 W., Big Horn County, Wyoming. (See Locality Map H.)

DOUBTFUL REFERRED SPECIMENS: YPM 5537, AMNH 8661? (See Discussion below.)

HORIZON: Unit V, approximately 50 feet (15.2 m) below Unit VI, Cloverly Formation.

KNOWN DISTRIBUTION: Unit V, Cloverly Formation, northern Wyoming.

DIAGNOSIS: Dental plate very large, broad and thin with four broad and apparently non-tuberculated radial ridges. The ridges are not sharp crested distally as in *C. guentheri*, nor do they extend to the medial margin of the plate. Externally, these ridges end in broad projections separated by shallow notches. Anterior ridge the largest, ends in the longest distal projection. Posterior ridge very faint, terminates distally in a very slight lateral projection. These radial ridges so subdued, apparently by excessive wear, that the typical ceratodontid radiating pattern is not clear, except near the external margin. Internal margin broadly rounded and not angled as in most other ceratodontids. Maximum length 58.5 mm, greatest width 28 mm, greatest thickness only 10 mm.

DISCUSSION: YPM 5276. As yet no analysis has been made of variation or ontogenetic differences in ceratodontid tooth plates. The situation is further complicated by the fact that wear appreciably alters the gross morphology of these tooth plates. Foundation of a new species on the present specimen would seem unwarranted under these circumstances, except for the fact that a large proportion of fossil lung fish are based on such isolated tooth plates. The Cloverly specimen is clearly distinct from any of the tooth plates known from the Morrison Formation, as well as from those of other North American Mesozoic species. Accordingly, until the range of variability, ontogenetic change, and effects of wear are clearly established the distinctiveness of the present specimen is best expressed by formal taxonomic designation.

YPM 5276 (Plate 9: A) is considerably larger than any of the Jurassic or Cretaceous ceratodontid specimens I have seen, and is almost as large as the largest Triassic plates, specifically those of *Ceratodus latissimus* from the Rhaetic and *Ceratodus runcinatus* of the Keuper (both of Europe). It is almost three times as large as the type of the Morrison species, *C. guentheri* (YPM 205) that measures 20 mm, 10 mm and 6 mm, respectively, in maximum length, width and thickness (Plate 9: B) and is at least twice as large as typical dental plates from the Morrison Formation. All of these specimens are distinct from *C. frazieri* in the presence of well-defined, sharp-crested ridges that extend nearly or entirely across the plate to the internal margin and in the deep notches separating the external extremities of these ridges. Also, the internal margins of Morrison specimens are moderately to sharply angled (Plate 9: B, C, D). There seems to be nothing distinctive about the size, spacing or arrangement of the dentinal osteons in *C. frazieri*. There is no evidence of a superficial enamel layer or of palial dentine, except along the external surface, and the tooth plate is composed almost entirely of osteodentine. The absence of enamel or palial dentine is presumably due to loss by wear, as evidenced by the subdued, broadly rounded topography of the radial ridges, the absence of tubercles, and the surprisingly thin construction of such a large plate.

C. frazieri is distinct from the fragmentary type of *C. robustus* Knight (1898), presumably from the Morrison Formation of Albany County, Wyoming, in the size and spacing of the external projections. The latter specimen, however, appears to be a palatal plate rather than a mandibular plate as described by Knight. *C. americanus* Knight (1898), also from the Morrison Formation, is based on an incomplete mandibular plate that corresponds very closely to Marsh's (1878) type of *C. guentheri. C. eruciferus* Cope and *C. hieroglyphus* Cope of the Fort Union (Hell Creek?) of Montana (Cope, 1876), and *C. crosbiensis* Warthin (1928) and *C. dorothea* Case (1921), both from the Triassic Dokum Formation of Texas, are much smaller (21 mm or less in length) and bear several more ridges than *C. frazieri.*

The present specimen is the only positive evidence of Dipnoi that we found during our extensive searches of Cloverly exposures—a surprising circumstance. A possible second specimen exists, however, and because of its interesting history and taxonomic importance, it warrants special comment.

"Ceratodus browni" (Wieland) Brown, 1938: p. 131

This specimen (AMNH 8661) was collected by Barnum Brown from the Cloverly Formation along Beauvais Creek in Big Horn County, Montana, a locale where we recovered extensive collections (see Locality Register of Appendix B and Locality Map U). Brown apparently thought it was invertebrate or plant and turned it over to the Curator of Invertebrate Fossils where it was catalogued as AMNH 24123. Wieland (1934) subsequently identified it and described it as a new species of shelf fungus, *Polyporites browni.* In 1938 Roland Brown of the United States National Museum suspected that Wieland's type specimen was not a fungus, and his subsequent investigations "resulted in the elimination of every available possibility except the dental plates of Jurassic and Cretaceous species of lung-fish, *Ceratodus.*" The correspondence, detail for detail, with these [fish] remains is so close that there is little, if any, doubt that *Polyporites browni* represents *Ceratodus.* The specimen is therefore renamed "*Ceratodus browni*" (Wieland) Brown, n. comb. (Brown, 1938: p. 131).

Article 2 of the International Code of Zoological Nomenclature states: "If a taxon is transferred to the animal kingdom, its name or names enter into zoological nomenclature with the original date and authorship." It seems to me that this would hold true *only* if other criteria of availability (Articles 10, 11, 12, 13, 14 and 15) are satisfied at the time of transfer. Article 13, for example, requires accompaniment of "a statement that purports to give characters differentiating the taxon—or a bibliographic reference to such a statement" for names proposed after 1930. It is absurd to consider Wieland's description establishing a fossil fungus as a distinctive diagnosis of a lungfish, and since Roland Brown failed to amend the description so as to distinguish his species of *Ceratodus* from other *Ceratodus* species, *C. browni* does not seem to satisfy the Code.

The type of *C. browni* (now recatalogued as AMNH 8661) unfortunately is a badly abraded fragment that cannot be referred with certainty to any animal group. No definitive gross character is preserved, the shape being entirely the result of broken or worn surfaces. There is no evidence of radial ridges or of lateral projections. Only the microscopic "polypore" structure exists and, although it does resemble that of lungfish tooth plates in a superficial way, it is not the same (see Plate 8: A). This specimen may well be a ceratodontid, but it certainly lacks all the usual diagnostic characters and is thus inadequate as a type specimen. I therefore consider *Ceratodus browni* a *nomen dubium.*

Subclass ACTINOPTERYGII

Order AMIIFORMES
Suborder ?AMIOIDEI
Plate 15: C-E

REFERRED SPECIMEN: YPM 5519, a partial left dentary of an indeterminate species.

LOCALITY: YPM 64-40, approximately 500 m east of Push Creek, Big Horn County, Montana. (See Locality Map R.)

HORIZON: Unit VII, 12 feet (3.6 m) above Unit VI, Cloverly Formation.

DESCRIPTION: The above specimen consists of a fragment of an edentulous left dentary which is generally similar to, but quite distinct from that of *Amia*. It appears to include part of the symphyseal surface, but this is uncertain because of abrasion. The length of the fragment is 37.5 mm, maximum vertical and transverse dimensions are 7 and 5 mm, respectively. It tapers very gradually anteriorly and is distinctively bowed, convex laterally. In cross-section, it is triangular with a sharp, narrow ventral apex that reflects a sharp-crested medio-inferior margin.

The external surface (Plate 15: E) is slightly convex both vertically and longitudinally and faces out and down. It is smooth and unsculptured, but there are a number of distinct foramina irregularly spaced and arranged in two poorly defined rows. The lower of the rows is the more prominent and appears to represent the mandibular lateral line. The internal surface (Plate 15: D) is more strongly convex (vertically) than the external surface and is marked by a narrow, shallow, open Meckelian groove just beneath the upper margin. There is no evidence whatsoever of a splenial or any other post-dentary element, nor is there is any indication of a median gular. The dorsal surface (Plate 15: C) is broad and gently convex, the width being nearly uniform throughout the length.

A total of 14 alveoli are arranged in a single row along the external margin of the dorsal surface and separated from the medial margin by a flat shelf 1 to 3 mm wide. The alveoli vary considerably in size but not in a regular or progressive manner. The sixth through ninth (from the front) alveoli are the smallest, ranging from 0.9 mm to 1.5 mm in minimum diameter, whereas those in front and behind are significantly larger. The 12th alveolus is the largest, measuring approximately 2.5 by 3 mm. This irregular variation in alveolar size may be comparable to the irregular size variation of marginal dentary teeth that is characteristic of amioids. Nearly all alveoli are oval, the transverse diameter being greater than the longitudinal dimension. The alveoli are not deep, but are regularly spaced and well defined. Tooth implantation was clearly subthecodont.

Despite the absence of both functional and replacement teeth, this fragment is well preserved. The alveolar dimensions relative to height and width of the fragment suggest that probably no more than 30 percent of the dentary is missing—if that much. This would indicate a mandible approximating 50 mm in maximum length.

DISCUSSION: With the fragmentary evidence at hand, it is impossible to assign the specimen with certainty. In shape, size, triangular cross-section and the line of external foramina it most closely resembles the dentary of *Amia*. It differs from the latter in its greater depth and robustness and in the absence of accessory teeth medial to the marginal tooth row. Although the fragment is possibly of amiid affinity, I have referred it questionably to the Amioidei.

Class REPTILIA

Order TESTUDINATA

Numerous fragments of turtle carapaces, plastra and limb bones are present in the Cloverly collections of the American Museum and the Peabody Museum. Most of these are not identifiable, but some are tentatively assigned here to the following taxa, chiefly on the basis of sculpture patterns.

Suborder CRYPTODIRA[2]

Superfamily BAENOIDEA Williams, 1950
?Family GLYPTOPSIDAE Marsh, 1890

Naomichelys Hay, 1908.

TYPE SPECIES: *Naomichelys speciosa* Hay, 1908.

TYPE LOCALITY: "25 miles east of Pryor, Montana"[3]; "Morrison Formation"?[4] (= AMNH 04-10?).

KNOWN DISTRIBUTION: Units V, VI and VII of the Cloverly Formation, Montana and Wyoming.

DIAGNOSIS: Same as for the type and only species.

Naomichelys speciosa Hay
Plate 9: E and F

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[2] Gaffney (1969) restricts usage of the term Amphichelydia to those early turtles that include the common ancestors of the Cryptodira and Pleurodira, as originally suggested by Lydekker (1889c). His study of the Baenoidea indicates a close relationship with the cryptodires and I follow Gaffney in placing the baenoids in the Cryptodira.

[3] This would place it in the vicinity of Beauvais Creek, near other Cloverly Formation sites of the American and Peabody Museums. (See Locality Map U.)

[4] Brown specified Morrison Formation in 1904 when he collected this specimen. The term Cloverly was proposed by Darton that same year and in subsequent years Brown referred to that part of the stratigraphic section exposed in the Beauvais Creek area as the Cloverly Formation. I have shown in a previous section (pages 44–45 and Measured Section 28, Appendix A) that there is very little of the Morrison Formation exposed in the Beauvais Creek area.

Naomichelys speciosa Hay, 1908.

TYPE SPECIMEN: AMNH 6136, entoplastron illustrated by Hay, 1908, Plate 40: figs. 2,3.

TYPE LOCALITY: "25 miles east of Pryor, Montana, Cloverly Formation" (= AMNH 04-10?).

REFERRED SPECIMENS: Right and left epiplastra (YPM 5385, 5431); fragmentary pleurals (YPM 5432, 5433, 5434); humerus head, femur head and many shell fragments (YPM 5437, 5518); shell fragments (AMNH 3052).

LOCALITIES: YPM 63-19, 64-18, 64-39, 64-56.

KNOWN DISTRIBUTION: Units V, VI and VII of the Cloverly Formation, Montana and Wyoming.

REVISED DIAGNOSIS: External ornamentation consists of variable, but generally closely spaced, cylindrical to oval tubercles or pustules ranging from 0.5 to 1.2 mm in diameter and 0.3 to 0.5 mm in height. The upper pustule surfaces flat to rounded and pustule bases constricted in diameter. Pustules commonly broken off leaving small circular scars. Arrangement appears to be random with no distinct lineation and adjacent tubercles do not coalesce. Entoplastron diamond shaped and slightly longer than wide. The posterior apex is longer than the anterior apex. Entoplastron slightly underlapped ventrally by the epiplastra and extensively overlapped by the hyoplastra. Ventral surface is marked by clear narrow sulci defining a long, narrow, wedge-shaped intergular and the medial portions of the humeral scutes. The intergular appears to have extended to the anterior extremity of the entoplastron, but falls short of the posterior extremity. Epiplastra variable with a very short interepiplastral suture and a broad ornamented marginal band on the dorsal surface. Epiplastra more robust (14 mm thick) than entoplastron. Sulci show the gular scutes to have been much longer in transverse dimension than in longitudinal dimension, and the posterior seam with the humerals is subparallel to the anterior epiplastron margin over much of the seam length. Pleurals inadequately known, but are relatively thin and not strongly arched transversely. Pleurals are not parallel sided, but taper slightly proximally. The rib is represented by a broadly convex ridge on the underside of the pleural.

DISCUSSION: These several isolated carapace and plastron elements are believed to belong to a single species, *Naomichelys speciosa*, because of the unusual ornamentation that is identical to that of the type specimen. Ordinarily I would consider such evidence unsound, but examination of numerous collections of Mesozoic turtles has revealed a conspicuous lack of ornamentation of this type. One specimen does suggest that this type of ornamentation may not have been constant. AMNH 3052, consisting of numerous shell fragments collected from 40 feet (12 m) below the Lakota (Unit VIII) at an unrecorded site at Middle Dome, Montana (Wheatland County), has this distinctive *Naomichelys* type of ornamentation. One fragment, however, has typical *Glyptops* type of sculpture and is devoid of pustules. There is no way to establish whether this solitary fragment is from a second specimen or a different region of the shell. I am inclined to favor the former on the grounds that no single fragment or specimen presently known shows gradation of *Naomichelys* and *Glyptops* types of ornamentation. Nevertheless, such gradation is possible and until more complete specimens are available, the following assignments are tentative.

In addition to the type specimen, which almost certainly is from the Cloverly Formation, several dozen fragments have been recovered from the upper part of that formation (Units VI and VII), all with the peculiar pustulose ornamentation. The type specimen corresponds very closely with the entoplastron of a nearly complete turtle (FMNH PR273) in the Field Museum collections from the Trinity Formation of Texas. The similarities include gross shape and dimensions, a long, narrow, wedge-shaped intergular and the same pustulose ornamentation that is present on all external surfaces of both the plastron and carapace. Interestingly enough, the Trinity and Cloverly Formations have been considered approximate correlatives for some time. The Chicago specimen has not been studied as yet, but it most probably is referable to *Naomichelys speciosa.*

Very similar pustulose ornamentation is also characteristic of the several species of *Tretosternon* from the Wealden of the Isle of Wight and Belgium. *Tretosternon,* which has arbitrarily been placed in the Dermatemydidae, may not be close to *Naomichelys*, but the similarity of sculpture is extraordinary. The only other chelonian that I am aware of with ornamentation of this general type is *Helopanoplia distincta* Hay (1908), a trionychid from the Lance Formation. In that species, the tubercles are more closely spaced, and commonly several tubercles are coalesced to form short, curved ridges. In the Cloverly specimens the spacing between tubercles is usually greater than tubercle diameter, and there seems to be no coalescing of adjacent pustules.

The two epiplastra (YPM 5385, 5431), although approximately of the same size, differ in several features. In YPM 5385 the ornamented marginal upper surface is broader than in 5431 and is marked by a distinct furrow in its lateral extremity. That part of the upper surface that is ornamented in YPM 5431 is convex throughout its length. The position of the gular-humeral sulcus differs also, with the gular scute overlying a large fraction of the epiplastron and extending over the entire marginal length of YPM 5385, whereas in YPM 5431 it covered a much smaller portion of the inferior surface and did not extend to the lateral extremity of the epiplastron. For the present, I consider these differences as individual variations and refer both varieties to *Naomichelys speciosa* until additional data are available.

Glyptops Marsh

Glyptops Marsh, 1890.

TYPE SPECIES: *Compsemys plicatulus* Cope.

Glyptops plicatulus Cope

Compsemys plicatulus Cope, 1877.
Glyptops ornatus Marsh, 1890.

TYPE LOCALITY: Garden Park, Colorado.

KNOWN DISTRIBUTION: *Atlantosaurus* beds (= Morrison Formation).

"Glyptops" pervicax Hay

Glyptops pervicax Hay, 1908.

TYPE SPECIMEN: AMNH 1910, incomplete carapace and nearly complete plastron, the latter figured by Hay, 1908, fig. 32.

TYPE LOCALITY: "Brush Creek", 10 miles (16 km) east of Pryor, Montana (see following Discussion).

REFERRED SPECIMENS: Incomplete plastron and carapace (AMNH 6071; YPM 4893, 4894, 4891, 4889, 5435, and 5277).

LOCALITIES: YPM 62-11, 62-13, and 66-3.

KNOWN DISTRIBUTION: Unit VII, Cloverly Formation and lower part of "Graneros" shale (Sykes Mountain Formation?), northern Wyoming and southern Montana (see following Discussion).

DISCUSSION: Except for AMNH 6071, none of the referred specimens are referable to *Glyptops pervicax* with certainty. All are too fragmentary. The faint, winding sculpture pattern, however, is similar to that of Hay's species. Gaffney (1969) has studied the type specimen and a referred specimen (AMNH 6071) and concluded that *"Glyptops pervicax"* is not determinable beyond assignment to the Baenoidea, but the ornamentation indicates it may be distinct from *G. plicatulus* and *Naomichelys*. Gaffney (personal communication) suspects that *G. pervicax* may be referable to a new genus he is describing from the Trinity Group of Texas.

At this date, more than 60 years after Barnum Brown collected the two American Museum specimens (AMNH 1910, 6071) there is little likelihood that the precise localities and stratigraphic positions will ever be determined. Hay (1908) gave Brown's locality for the type specimen as 10 miles (16 km) east of Pryor, Montana on "Brush Creek". The records in the American Museum catalogue read the same. That region was extensively explored by our field parties, and I myself am very familiar with the area. At present there is no stream in the area known as "Brush Creek". Although we cannot establish the name in use in 1903, the name Push Creek is now applied to the first major tributary of Beauvais Creek, 13 miles (20 km) almost due east of Pryor. Outcrops along the lower 2 miles (3.2 km) of Push Creek consist of the Morrison, Cloverly, Sykes Mountain, and Thermopolis Formations. Thus, it appears probable that "*Glyptops pervicax*" came from either the Sykes Mountain (rusty beds) or the lower part of the Thermopolis Shale (rather than the Graneros Shale as indicated in American Museum records) from somewhere along Push Creek. The second specimen apparently came from the Sykes Mountain Formation in the vicinity of Cashen ranch on Beauvais Creek, approximately 25 miles (40 km) east of Pryor. Other fragments obtained by Yale expeditions were all found in the uppermost unit

(VII) of the Cloverly Formation from several localities in Wyoming. On the basis of these tentative identifications, it appears that at least one Cloverly taxon may have survived the initial marine transgression.

SUBORDER CRYPTODIRA

?FAMILY *incertae sedis*

Plate 9: I-L

DESCRIPTION: A large turtle is represented by the proximal and distal ends of a large right humerus (YPM 4900; locality YPM 63-27). The shaft is missing so length and complete form are not known. Morphologically, these fragments (Plate 9: I-L) compare most closely with certain living emydines, particularly *Terrapene* and *Clemmys*, and appear to represent a large terrestrial or semiaquatic tortoise. Except for the much larger size, the fragments are identical, point for point, with the humerus extremities of *Terrapene*: the oval, and slightly twisted head, the broad and sharply defined external (anterior) shelf facet adjacent to the head, the large, tapered internal tuberosity and the smaller deltopectoral crest at nearly right angles, and positioned proximally, close to the head, the short but deep fossa between these proximal processes, the sharply defined and raised trochlear surface extending slightly onto the dorsal surface, the relative sizes and convexities of the radial and ulnar condyles, the form and location of the ectepicondyle foramen and groove, and the reduced size of the ent- and ectepicondyles. In several of these features there is a close comparison with *Glyptops plicatulus*?, but in the latter the head is more nearly spherical, the long axis of the head is perpendicular to the deltopectoral crest rather than oblique, and the external articular shelf is narrow and not so sharply defined. The internal tuberosity and deltopectoral crest also are of different shape, and the deltopectoral crest is relatively more massive and at more than 90° to the internal tuberosity in the present specimen. Also, the ectepicondyle and entepicondyle are larger in the present specimen and the trochlea more expanded with both condyles being well rounded, but the radial condyle is the smaller of the two. The proximal ectepicondyle foramen is situated well proximal to the trochlear facet, in contrast to *Glyptops plicatulus*, and the entepicondyle is much larger in *Glyptops*. The only feature (other than size) that appears to distinguish the specimen from *Terrapene* is a moderate-sized, deep fossa on the dorsoanterior surface of the deltopectoral crest. I have not recognized this condition in any other turtle.

LOCALITY: YPM 63-27.

HORIZON: Unit VII, Cloverly Formation.

DISCUSSION: These fragments cannot be assigned to any family with certainty, but they suggest testudinid affinities. If correct this would be the earliest record of that family. Hay (1908) described *Gyremys spectabilis*, from a carapace and plastron from the Judith River Formation, as an emydid (= testudinid) and Estes (1964) tentatively assigned some shell fragments from the Lance Formation to the Emydinae.

ORDER ?TESTUDINATA

FAMILY *incertae sedis*

Plate 9: G and H

DESCRIPTION: The distal end of a left humerus (YPM 4903) from Unit VII, locality YPM 63-28, appears to represent a fourth chelonian family, although it cannot be referred even to this order with absolute certainty. The distal end is compressed dorsoventrally so that the breadth (24.5 mm) is more than twice the thickness (11 mm). There is no sign of a trochlear facet, the entire distal surface is broadly convex both transversely and vertically with only a slight concavity at the middle of the ventral margin to show the subequal radial and ulnar surfaces. The broad, nontrochlear form would appear to rule out the pleurosternids. The shaft appears to have been moderately arched and tapered to a thin cylinder (10 mm) near midlength, a condition which eliminates highly aquatic turtles. The ectepicondylar foramen has been lost, but a long, deep groove extends down the middle of the anterior shaft surface and turns sharply downward across the articular surface. Although different in several details, this fragment most closely approaches the humeral morphology of some pelomedusids, particularly that of *Podocnemis*. Numerous specimens of Late Cretaceous age have been referred to the Pelomedusidae, but the present specimen is totally inadequate for definite assignment, and I am not suggesting that it represents an Early Cretaceous member of that family.

LOCALITY: YPM 63-28.

HORIZON: Unit VII, Cloverly Formation.

ORDER CROCODILIA
SUBORDER MESOSUCHIA

FAMILY *incertae sedis*

Plate 10: A-D

DESCRIPTION: Crocodilian remains are not very abundant in the upper three units of the Cloverly Formation. Whether this indicates that Cloverly-age crocodilians were less aquatic and more terrestrial in their adaptations, or simply less common, is not known. They do not constitute a major fraction of the known fauna. Numerous isolated teeth, vertebrae, dermal scutes and limb bones were collected at a large number of the Yale localities. The vertebrae all appear to be referable to the platycoelous Mesosuchia, but the teeth and scutes cited here may include representatives of the Eusuchia. None of these remains are adequate for definite assignments, so only brief comments are appropriate.

Teeth. The referred teeth are of two basic types, relatively long, slender, straight or slightly curved cones and short, blunt, circular to oval "buttons". With the exception of two of the former (YPM 5440, 5448), all have moderately to strongly developed ridges and grooves on all sides.

REFERRED SPECIMENS: Isolated conical teeth (YPM 4884, 4890, 5343, 5345, 5346, 5348, 5353, 5354, 5358, 5361, 5362, 5363, 5364, 5372, 5381, 5438, 5439, 5443, 5444).

LOCALITIES: YPM 62-5, 62-11, 63-16, 63-18, 63-19, and 64-18.

HORIZONS: Units VI and VII, Cloverly Formation.

The tapered cones have two straight and rather prominent ridges, one on each side. The remaining ridges usually are most strongly developed on the concave surface and less prominent on the convex (external) surface. The two exceptions mentioned above may be variants of the more common type, but both are characterized by very pronounced, curved, anterior and posterior ridges, and an absence of other ridges. The more common, simple conical teeth range from less than 8 mm to more than 35 mm in height and up to 14 mm in basal diameter. In general, the ridges and grooves are most pronounced on the largest teeth, but not all large teeth are equally prominent in this sculpture. However, they do not differ in any significant way from the ubiquitous crocodilian teeth from the Morrison Formation that are commonly referred to "*Goniopholis*" (Plate 10: A).

REFERRED SPECIMENS: Isolated teeth (YPM 5342, 5344, 5359, 5447).

LOCALITY: YPM 63-19.

HORIZON: Unit VII, Cloverly Formation.

The blunt, buttonlike teeth, most probably posterior teeth, are represented by only eight isolated teeth from a single locality (YPM 63-19). All show faint wrinkling of the sides and all are inflated above the base. The sizes range from less than 2 mm to about 9 mm in maximum diameter. I am unable to find significant differences in these from the posterior teeth of modern *Alligator* (Plate 10: B).

REFERRED SPECIMENS: Isolated vertebrae (YPM 4883, 5110, 5128, 5129, 5172, 5292, 5293, 5384, 5398, 5412, 5414, 5415, 5425, 5429, 5445, 5530).

LOCALITIES: YPM 62-5, 63-18, 63-19, 64-3, 64-18, 64-23, 64-61, 64-63, 64-70, 64-71.

HORIZONS: Units VI and VII, Cloverly Formation.

Several isolated vertebrae, including three caudals (YPM 5110, 5172, 5445) and centra of a dorsal and cervical (YPM 5129, 5128), are tentatively referred to Crocodilia. The caudals are of differing size and length and appear to represent different segments of several individuals. All are platycoelous with rather flat lateral surfaces and a shallow, broad, ventral groove on the underside of the centrum. Robust transverse processes occur at the level of the neural canal and anterior to centrum midlength (Plate 10: C and D).

The dorsal and cervical centra are also platycoelous, the latter with rather robust parapophyses and a prominent ventral ridge (but not a keel).

REFERRED SPECIMENS: Limb fragments (YPM 5401, 5412; 5436; AMNH 5852).

LOCALITIES: YPM 63-16, 64-18, 66-3; AMNH 03-26.

HORIZONS: Units VI and VII, Cloverly Formation.

From Yale locality 66-3, the proximal end of a left femur (YPM 5436) was collected. Although it is not possible to assign this to a particular genus, it does not differ in any significant way from femora of various sizes from the Morrison Formation that have usually been referred to *Goniopholis*. That genus is presently under study by Dr. Wann Langston, and any reference of material to *Goniopholis* at this point would be questionable. Of particular interest, though, regarding the present specimen is the fact that it is identical with the femur of *Alligator mississippiensis* but is clearly distinct from *Crocodylus*. Extrapolating from Recent *Alligator*, the fragment is from a femur approximately 13 cm long and represents an animal about a meter and a half in length.

Associated with this specimen was another fragment that appears to be the proximal end of a left tibia, but it is too poorly preserved and incomplete to warrant further comment.

The proximal and distal ends of a much smaller crocodilian femur (YPM 5412) were recovered from Yale locality 64-18. The original bone did not exceed 6 cm in length and represents remains of the smallest individual crocodilian found in the Cloverly Formation.

A variety of crocodilian scute fragments were recovered from a number of localities, particularly the quarries at Crooked Creek. All feature the deep, circular to oval, pitted type of sculpture. None were characterized by a keel. An incomplete metatarsal (YPM 5401), probably the fourth from a left pes, was also recovered at a Crooked Creek site (Locality YPM 63-16).

The best crocodilian specimen, purportedly from the Cloverly Formation, is AMNH 5852, from an unknown locality (AMNH 03-26) somewhere along Beauvais Creek on the Crow Reservation. This specimen, apparently surface scrap, consists of hundreds of chips and fragments heavily encrusted with hematite; included are two dorsal centra, a sacral centrum, most of both humeri, a right femur, part of the left femur, the right tibia, right coracoid, proximal end of the right radius, proximal end of the right scapula, the pubic peduncles of both ilia, part of the right ischium, parts of both lower jaws and dozens of scutes with numerous deep circular pits.

The femur matches that described above (YPM 5436) and those referred to *Goniopholis* from the Morrison Formation. Femur length is about 18.5 cm. As with YPM 5436, it corresponds closely with the femur of *Alligator*, except that the shaft is slightly less robust, the fourth trochanter is less prominent, and the size and position of the insertion of the M. caudi–femoralis longus is smaller and more distally placed.

The tibia is distorted, but its original length was approximately 16 cm. It also appears less massive than the tibia of *Alligator*, but no other details can be observed due to the distortion and the encrusting hematite. Neither humerus is complete and both have suffered from crushing, but the right humerus had an original length of close to 20 cm. If correct, this means the humerus was longer than the femur, a trait that would be unique among crocodilians. Like the hind limb elements this bone was also less robust than that of *Alligator*. There are other differences from *Alligator*; specifically, the radial condyle is larger than the ulnar condyle and it is bordered by a short anterior ridge at its anteroinferior margin, the proximal end is also less expanded anteroposteriorly.

The remaining fragments show few other features that differ from *Alligator*. The anterior blade of the coracoid appears to have been thinner and longer and the pelvic elements appear to have been relatively larger, but the material is too fragmentary to be certain. The jaw fragments contain several "*Goniopholis*" type teeth.

The vertebrae are similar to the other isolated vertebrae cited above, except that the two dorsals bear slight, midline bosses on the ventral surfaces close to the anterior margin. These may be posterior remnants of the ventral sagittal keel that is characteristic of Recent crocodilian cervicals and anterior dorsals, but, if so, there are no similar features in living crocodilians except in the cervicals, and neither of these centra are cervicals. Both are platycoelous to amphiplatyan, subcircular in end view and concave longitudinally in both ventral and lateral surfaces.

As with the preceding material, this specimen cannot be assigned with certainty to any genus.

ORDER SAURISCHIA
SUBORDER THEROPODA

FAMILY DROMAEOSAURIDAE Matthew and Brown, 1922

Dromaeosaurinae Matthew and Brown, 1922.
Dromaeosauridae Matthew and Brown, Ostrom (1969a).

REVISED DIAGNOSIS: Small to moderate-sized theropods, lightly built and bipedal in posture. Fore limb not reduced. Manus long and slender with three functional digits. Digit III moderately divergent and carpus highly specialized with asymmetrical ginglymus on radiale. Hind limb moderately long, pes of moderate length and functionally didactyl. Digit II modified as an offensive or predatory weapon with large trenchant claw. Digits III and IV subequal and normal, digits I and V reduced. Caudal series may be modified by extremely long prezygapophyseal and chevron processes that rendered the tail virtually inflexible throughout most of its length.

KNOWN DISTRIBUTION: Late Aptian or Early Albian to Late Campanian or Early Maestrichtian, western interior of North America and central Asia.

COMMENT: Matthew and Brown first used the term Dromaeosaurinae in 1922 for reception of their newly described theropod species, *Dromaeosaurus albertensis* from the Belly River Formation (Oldman) of Alberta, which they provisionally referred to the Deinodontidae (Tyrannosauridae). Gilmore (1924, 1933) and Kuhn (1966) accepted this classification, but few other students have recognized the category. Most authors have in fact not accepted the deinodont assignment and have referred *Dromaeosaurus* to the Coeluridae, Coelurosauridae or Compsognathidae (probably because of its small size more than anything else). Discovery of the following material and its clear affinities with *Dromaeosaurus* has established the validity of a supra-generic category, so I have proposed (1969a) elevation of Matthew and Brown's Dromaeosaurinae to family rank. Related species that may be included in the family (see Ostrom, 1969a and b) are *Stenonychosaurus inequalis* Sternberg (1932), *Velociraptor mongoliensis* Osborn (1924) and *Saurornithoides mongoliensis* Osborn (1924). This new rank was also adopted by Colbert and Russell (1969) in their study of *Dromaeosaurus.*

Deinonychus Ostrom

Deinonychus Ostrom, 1969.

TYPE SPECIES: *Deinonychus antirrhopus* Ostrom, 1969.

TYPE LOCALITY: YPM 64-75, NE ¼ Sec. 17, T.7 S., R.24 E., Carbon County, Montana. (See Locality Map L.)

KNOWN DISTRIBUTION: Cloverly Formation, Units V, VI and VII, northern Wyoming and southern Montana.

DIAGNOSIS: Same as for the type species.

Deinonychus antirrhopus Ostrom
Plate 10: E-M

Deinonychus antirrhopus Ostrom, 1969.

TYPE SPECIMEN: YPM 5205, left pes illustrated by Ostrom, 1969a, figs. 1-3.

TYPE LOCALITY: YPM 64-75, NE ¼ Sec. 17, T.7 S., R.24 E., Carbon County, Montana. (See Locality Map L.)

REFERRED SPECIMENS: YPM 5201-5204, 5206, 5379, 5356, 5366, 5371, 5376, 5420, 5441, 5278, 5279, 5280, 5281, 4886, 4887, 5283, 5399, 5275, 5287, 5288, 5289, 5290, 5291, 5397; AMNH 3015, 3037, uncatalogued teeth associated with AMNH 3041, and uncatalogued teeth with AMNH 3034.

LOCALITIES: YPM 62-6, 62-14, 63-18, 63-19, 64-18, 64-27, 64-33, 64-41, 64-52, 64-53, 64-64, 64-65, 64-67, 64-72, 64-74, 64-75; AMNH 32-5, 32-8, 33-1.

KNOWN DISTRIBUTION: Units V, VI and VII of the Cloverly Formation, north-central Wyoming and south-central Montana.

DIAGNOSIS: See Ostrom, 1969a, 1969b.

DISCUSSION: A detailed description of the species has been presented (Ostrom, 1969b) so additional description is not necessary here. The distribution is extended to include 16 new localities ranging from Shell Creek (Big Horn County, Wyoming) to Middle Dome (Wheatland County, Montana). Most of the materials consist of isolated teeth or fragmentary elements that can be referred with certainty to *D. antirrhopus* on the basis of the very large collection obtained at locality YPM 64-75. The teeth are all characterized by a pronounced size discrepancy between the serrations of anterior and posterior carinae, a feature that appears to be unique to *Deinonychus* and related forms of later Cretaceous age.

Although the majority of the localities listed produced fragmentary, isolated elements, this species would seem to have been moderately abundant. It is by far the most common theropod, and appears to have been the third most abundant element in the Cloverly megafauna.

FAMILY ORNITHOMIMIDAE Marsh, 1890

Ornithomimus Marsh

Ornithomimus Marsh, 1890.

TYPE SPECIES: *Ornithomimus velox* Marsh, 1890. (See my Plate 11: A-E.)

TYPE LOCALITY: SW ¼ Sec. 27, T.4 S., R.69 W., Jefferson County, Colorado.

KNOWN DISTRIBUTION: "Denver Formation", Colorado.

Ornithomimus sp.

Plate 11: F-J

REFERRED SPECIMENS: Incomplete left metatarsal II (YPM 5174); incomplete left metatarsal IV (YPM 5284); fragment of a proximal pedal phalanx (AMNH uncatalogued); and a pedal ungual (YPM 5286).

LOCALITIES: YPM 63-16, 63-18; AMNH 55-1 or 2 ("Beauvais Creek, Montana"); and YPM 64-3.

KNOWN DISTRIBUTION: Unit VII, Cloverly Formation of northern Wyoming and southern Montana.

DESCRIPTION: Reference of these fragmentary remains to Marsh's genus may seem questionable, but the near identity of the two metatarsal fragments to Marsh's type specimen of *O. velox* is so striking that any other action would be highly misleading. The two metatarsal fragments are from different size individuals and were collected from different quarries nearly 100 meters apart.

Metatarsal II (YPM 5174) is approximately 50 percent larger than that of *O. velox* but otherwise is virtually indistinguishable from the latter (see Plate 11: C and H). The distal articular facet is a bulbous convexity with a broad and relatively deep inferior medial fossa or groove dividing two divergent condyles. However, the surface is not ginglymoid. A shallow concavity marks the inner side and a deep oval collateral ligament fossa marks the external surface. The shaft is subcircular in section with moderately well-defined, flattened surfaces internally, externally and inferiorly. These flattened shaft surfaces are somewhat less pronounced and less well defined in the Cloverly specimen than in Marsh's type specimen. The proximal end is missing, consequently the length is unknown, but it almost certainly exceeded that of *O. velox* (YPM 542) in which the minimum length of the third metatarsal is 22.2 cm. The incomplete length of YPM 5174 is 16 cm.

The fourth metatarsal (YPM 5284) is from a smaller individual approximately 15 percent larger than the type of *O. velox* (Plate 11: A, B, F and G). The distal facet is almost triangular in end view, as in *O. velox*, and strongly convex and not ginglymoid. Inferiorly, the facet is extended into a robust internal condyle and a long, thin external condyle, separated by a shallow depression. The external distal surface is marked by a shallow depression, the inner surface by a well-defined oval fossa, precisely as in *O. velox*. The midshaft is strongly flattened on the ventral and internal surfaces. The incomplete length is 23.5 cm, compared with an incomplete length of 16.5 cm in *O. velox* (YPM 542).

An isolated incomplete ungual (YPM 5286) of small size (3.5 cm probable maximum length) is clearly distinct from those of all other Cloverly taxa. It is nearly straight, with a straight-sided narrow taper. The underside is broad and flat, the upper surface is sharply rounded. A very slight flexor tubercle is present immediately distal to the lower margin of the ridged articular facet. Although not identical to ornithomimid foot claws, it compares best with *Ornithomimus velox* and is tentatively referred to that genus (see Plate 11: I and J).

DISCUSSION: Osborn (1917) proposed the name *Struthiomimus* "for the Belly River (Fort Pierre) stage of the Ornithomimidae" to distinguish material in the American Museum (AMNH 5339) and National Museum of Canada (NMC 930f) from the Belly River Formation of Alberta from Marsh's specimen of possible younger age from the "Denver Formation, 12 miles from Denver, Colorado". One of the distinctive features cited by Osborn for *Struthiomimus* was the retention of the fifth metatarsal, whereas *Ornithomimus* is distinguished "by the loss of metatarsal V in the pes, for which no facet remains." Osborn further justified *Struthiomimus* on the grounds that it was improbable that a genus would persist from the *Monoclonius–Ceratops* zone (= Belly River, Judith River) into the *Triceratops–Torosaurus* zone (=Hell Creek, Lance, Denver).

I agree with Gilmore (1920) that these are inadequate bases for proposing a new genus, particularly in view of the fact that the precise age of *Ornithomimus velox* is debatable. Moreover, I would like to point out that the absence of the fifth metatarsal in YPM 542 is negative and inconclusive evidence. Examination of the proximal end of the type metatarsal IV reveals the presence of a distinct notch in the posterior margin, the location and surface of which is highly suggestive. I suggest that a fifth metatarsal probably was present and occupied this notch in *O. velox,* and until further evidence of the distinctiveness of the various relevant materials, I prefer to use the name *Ornithomimus.* In the absence of distinctive characters in the few existing Cloverly specimens, I have referred them to Marsh's genus until more data are available.

The occurrence of ornithomimid remains in the Cloverly Formation may come as a surprise, but Gilmore (1919, 1920, 1921) established the probable existence of ornithomimids in North America by Early Cretaceous times in his analysis of the collections from Arundel Formation of Maryland. He (1920) designated as co-types of *Ornithomimus affinis* several isolated foot bones (USNM 5703, 5704, 5453, 5684, 8456) that Marsh (1888) had designated as co-types of *Allosaurus medius* and that Lull (1911) transferred to the Orthopoda (= Ornithopoda) as *Dryosaurus grandis.* As Gilmore demonstrated (1920), these bones are not ornithopod and they do not compare closely to the corresponding elements of *Allosaurus.*

?FAMILY MEGALOSAURIDAE Huxley, 1870

Plate 10: N

REFERRED SPECIMENS: Isolated teeth of medium to large size (YPM 5369, 5377, 5378, 5379); a single dorsal vertebra (YPM 5285); a metatarsal fragment (YPM 4885); a dorsal neural arch (YPM 5408); an angular (YPM 5538).

LOCALITIES: YPM 62-6, 63-16, 63-18, 63-19, 64-3, 64-59.

HORIZONS: Units V, VI and VII, Cloverly Formation.

DESCRIPTION: *Teeth.* The few teeth represented in the present collections are of medium and large size (27, 29, 71 and 80+ mm in height). The moderate-sized teeth are significantly larger than the largest teeth of *Deinonychus*, but most important, none have the pronounced size discrepancy between denticles of anterior and posterior serrations. All are transversely compressed, slightly curved, narrowly tapered blades that are not significantly different from megalosaurid or tyrannosaurid teeth. The much larger teeth in all probability represent another larger species, but neither of these probable taxa can be defined on present materials.

A metatarsal (YPM 4885) is represented by a fragment of the distal extremity that I tentatively refer to the Megalosauridae. The only lateral surface preserved is marked by a deep oval, collateral ligament fossa. The incomplete trochlear surface is only slightly grooved and not strongly ginglymoid. Both of these features compare closely with those of the third metatarsal of *Allosaurus*, but not *Deinonychus* or *Ornithomimus*. The fragment measures 48 mm in its greatest (incomplete) height, and the distal width probably approached 50 mm.

Vertebra. A solitary dorsal vertebra (Fig. 6) collected at YPM 64-59, from the upper part of Unit V, compares reasonably well with middorsals of *Allosaurus*, with the exception that it is not as narrow-waisted as the latter and the neural spine is unique. The centrum is constricted laterally and ventrally, and the ends flare out broadly, as in all large theropods. The anterior centrum face is slightly concave, the posterior face is moderately concave. Both ends are nearly circular with vertical and horizontal diameters equal and only slightly less than centrum length (103 mm). These features suggest an anterior dorsal, if we can extrapolate from centrum height-length and the form of centrum faces in *Allosaurus, Ceratosaurus* and *Acrocanthosaurus*. There are no pleurocoels and in this feature YPM 5285 resembles dorsal vertebrae of *Allosaurus* and *Megalosaurus* and is distinct from most other large theropods, including *Acrocanthosaurus*, although the dorsal series is not completely preserved in the type specimen of the latter.

The neural arch is distorted and the diapophyses are incomplete, but the basic form and dimensions are preserved. Most distinctive is the neural spine which is nearly complete with the summit, anterior and posterior margins intact. The low and robust bladelike neural process expands upward, the longitudinal length at the summit being nearly twice that of the spine base (8 cm vs 4.5 cm). The anterior and posterior margins are heavily rugose over their entire lengths, marking the attachment of thick, strong interspinous ligaments. The spine crest is rounded transversely and nearly straight longitudinally. The summit is not expanded transversely as in all other large theropods, but the spine does expand near the anterior and posterior margins; conse-

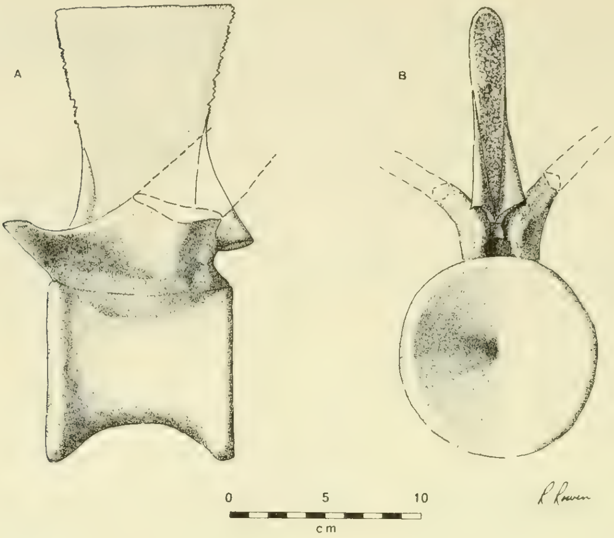

FIG. 6. Reconstruction of an indeterminate theropod dorsal vertebra in lateral (A) and posterior (B) views.

quently, the spine is thin near the center of the blade and thickest at the anterior and posterior edges. Maximum height of the neural spine is about 9 cm, or less than centrum length. The diapophyses appear to have been thin blades about 6 cm wide that flared out, up and back at perhaps 20° to the horizontal. The zygapophyses are small (2 cm long), close to the midline and the facets are inclined at about 45°. The arch pedicels are robust and low, extending the full length of the centrum.

DISCUSSION: None of these specimens is adequate for generic assignment, but they clearly establish the presence of moderate- and large-sized theropods in the Cloverly fauna. Reference to the Megalosauridae may be debatable in view of the fragmentary nature of the remains, but *bona fide* tyrannosaurid remains are known only from Late Cretaceous strata. Further support of this assignment is the nonpleurocoelous condition of YPM 5285, an apparently rare condition in large theropods that is known only in a few megalosaurids (*Allosaurus* and *Megalosaurus*).

The vertebra is distinct from known dorsals of *Acrocanthosaurus atokensis* from the Trinity Formation of Oklahoma in the absence of pleurocoels, in the circular and more concave faces of the centrum and the normal neural spines of *A. atokensis.* It cannot be compared with the type of *Dryptosaurus*? *potens* (*Creosaurus potens* Lull, 1911) from the Arundel Formation of Maryland (see Gilmore, 1921 and page 126 of this report), an anterior caudal centrum (USNM 3049). However, the fact that the latter is not deeply constricted laterally and ventrally suggests that the dorsals may have had similar form and thus have been distinct from the present specimen.

FAMILY COELURIDAE Marsh, 1881

Microvenator, new genus

ETYMOLOGY: *Mikros* (Greek), small, and *venator* (Latin; masculine), hunter.

TYPE SPECIES: *Microvenator celer,* new species.

DIAGNOSIS: Same as that of the type and only species.

Microvenator celer, new species
Plate 11: L-N; Plate 12: A-P; Plate 13: A-E

ETYMOLOGY: *Microvenator celer,* (Latin), swift, in reference to the probable rapid-running capabilities indicated by the tibia-femur ratio.

TYPE SPECIMEN: AMNH 3041, a partial skeleton, lacking the skull.

TYPE LOCALITY: AMNH 33-1, SW ¼ Sec. 26, T.7 N., R.16 E., Wheatland County, Montana.

HORIZON: Unit VII, 60 feet (18 m) below Unit VIII, Cloverly Formation.

REFERRED SPECIMENS: YPM 5366?.

LOCALITIES: YPM 63-19.

DISTRIBUTION: Unit VII(?), Cloverly Formation, central Montana and northern Wyoming.

DIAGNOSIS: Very small, delicately built coelurid with hollow thin-walled vertebrae and limb bones. Cervicals without neural spines and with double pleurocels. Dorsal neural arches low and highly sculpted, neural spines low and rectangular, postzygapophyses far behind posterior border of centrum. Astragalus with very high and broad ascending process. Pubis profile concave anteriorly, distal extremities only moderately expanded. Femur with short but prominent lesser trochanter and a depression at site of fourth trochanter. Approximately one half to two thirds the size of *Ornitholestes* or *Coelurus.*

DESCRIPTION: *Skull.* A number of thin and extremely delicate fragments are all that are preserved of the skull. Most of these are not identifiable, but those that are include a right palatine, both quadrates, both postorbitals(?) and a right prearticular (?). The incomplete palatine is triangular. The anterior margin preserves the broad posterior limits of the choana between the maxillary and pterygoidal processes. The posterior portion is missing, but the inner margin appears to be intact and suggests the presence of a subsidiary palatal fenestra between the palatine and the pterygoid, as in *Deinonychus* and *Ornithosuchus.* Maximum dimensions are 32.5 mm in length and 23 mm in width.

The fragments identified as postorbitals are robust and moderately curved. The external surface is strongly convex, the inner slightly concave. There appears to be no ornamentation, sculpture or rugose texture. The extremities are missing in both fragments. The quadrates are not complete, the pterygoid wing being absent in both and the upper and lower extremities somewhat abraded. The lower extremity is triangular in outline and quite robust. The anterior surface is deeply concave and bordered by sharp lateral and medial crests, the latter presumably continued as the pterygoid wing. The upper extremity is a thin blade apparently oriented in a near parasagittal plane. Contact with the squamosal appears to have been of an overlapping, squamose union. Preserved lengths of the quadrates are 22 and 23 mm, but original length was probably 30 mm or more.

Axial skeleton. The vertebral count is not known. Sixteen presacral neural arches are preserved, plus 10 presacral centra or centra fragments (Pl. 11: L-N; 12: A-F). One of the latter is the axis centrum, for which no arch is present. Thus at least 17 presacral segments are represented. A normal presacral count of 23 is assumed. Only three centra and four neural arches are clearly recognizable as cervicals. The remainder appear to be dorsals. All presacral centra are pleurocoelous. The cervicals have one large lateral cavity in the anterior half and a smaller one behind at near midlength of the centrum. The dorsals have a single, smaller pleurocoel on the lateral centrum surface at midlength. The cervicals appear to have been opisthocoelus and the centra were moderately to strongly angled as in *Deinonychus*, but the centra are longer relative to height and width than in *Deinonychus*. In this latter character they are more like cervicals of *Coelurus* (YPM 2010). Lengths and widths of the axis and other cervical centra are: 14 by 7.5 mm, 15 by 10 mm and 15 by 10.5 mm. The cervical neural arches are broad and low with long zygapophyses flaring out anteriorly and posteriorly in a nearly horizontal plane. The articular facets are widely separated (15 mm or more) and appear to have been inclined at 30 to 45° to the horizontal. The postzygapophyses lie far behind (6 mm) the posterior end of the centrum. None of the cervical neural arches show any indication of a significant neural spine, a very low ridge being the only evidence preserved.

The dorsal vertebrae are platycoelous with moderately constricted lateral and ventral surfaces of the centra. Centrum length varies from about 13 mm to 16 mm, but width and height increase from about 9 mm (anteriorly?) to 15 by 10 mm (posteriorly?). The neural arches are of moderate height, quite robust and intricately sculptured. The pedicels and transverse processes are constructed of various struts and ridges separated by numerous deep cavities. The transverse processes appear to have been short (total arch width is 17 to 20 mm) and extended directly lateral in a horizontal plane. A short, robust, rectangular neural spine rises vertically directly above the centrum. Spine height varies from 6 mm to 15 mm in the dorsal arches preserved. Articular facets lie close to the sagittal plane but are inclined at approximately 45°. The posterior facets are situated far behind the pedicels (8 mm), whereas the prezygapophyses are placed directly above the anterior limits of the neural arch pedicels. Several arches appear to show remnants of hyposphene–hypantrum articulations.

The sacrum is represented by a broad, shallow centrum approximately 15 mm long. It appears to have been greatly distorted, although it may originally have been more compressed than the other centra. Caudal vertebrae are represented by nine centra, some with arches, and three additional neural arches. All are platycoelous and are moderately constricted near midlength. None have pleurocels. Proximal caudal centra show evidence of stout transverse processes projecting out from the middle or anterior part of the lateral surfaces. Most appear to be compressed dorsoventrally so that centrum width is nearly double the height, and the centra faces are thin, horizontal ovals. Centrum length varies from 12 mm to less than 9 mm in the caudal vertebrae available.

Appendicular skeleton. The scapula is not known, but a nearly complete right coracoid is present. This is an extremely thin sheet of bone nearly semicircular in outline. Proximally it expands into a stout ridge that forms the anterior limit of the glenoid. The posterior margin is thickened slightly, but otherwise shows no evidence of sutural or even solid contact with the scapula. The coracoid measures 32 mm in greatest vertical dimension and 25.5 mm in length.

The fore limb is represented by the left humerus, radius and ulna, a fragment of the right ulna and six elements from the left manus (see Plate 12: G-J, and L). The humerus is slender and rather straight. The head is small and projects backward almost at right angles to the long axis of the distal condyles. A small internal tuberosity borders the head medially and a large deltopectoral crest projects anteroexternally along the upper third of the humeral shaft. Although postmortem distortion may have contributed to the present form, the deltopectoral crest projects much more laterally and far less anteriorly than is usual in small theropods. In *Coelophysis, Coelurus, Ornithomimus* and *Deinonychus*, for example, this crest projects forward almost parallel to the plane of flexion at the elbow. In the present specimen, it extends at approximately 45° to that plane. The distal extremity is slightly crushed but the radial condyle appears to have been the larger of the two. Humerus dimensions are: length – 81.5 mm; width across deltopectoral crest – 21 mm; greatest distal dimension – 13 mm; minimum shaft diameter – 6 mm.

The ulna is a very slender and delicate bone; the shaft has moderate curvature convex externally, and measures 78 mm in length and 3.5 mm in minimum diameter. The proximal end is expanded anteroposteriorly (8.3 mm) and the surface is inclined medially. The distal extremity is also expanded (9.4 mm) anteroposteriorly. The radius is also very delicate and slender, with a nearly straight uniform cylindrical shaft 3.5 to 4.5 mm in diameter. Neither end is intact so original length is not known, but it probably did not greatly exceed the preserved length of 75 mm. Both extremities seem to have been at least slightly expanded.

The manus is represented by six elements: metacarpal I, the penultimate phalanx of digit II, the distal end of an indeterminate phalanx and three claws of different sizes, presumably representing digits I, II and III. Judging from the lengths of the complete phalanx and the claws, metacarpal I appears to have been of normal theropod proportions and not elongated as in ornithomimids. However, it does seem relatively longer (17.5 mm) and more slender (2.5 mm) in construction than do those of most theropods. The proximal end is triangular, slightly twisted relative to the distal ginglymus and has a large external appositional scar for contact with the second metacarpal. The complete phalanx would seem to be too long (34 mm) relative to metacarpal I to be any other phalanx except the second of digit II, but this must remain a tentative identification. The claws are thin and trenchant, and strongly curved. The largest (II?) measures 25 mm long and 3.5 mm in maximum thickness. The others measure 19 by 2 mm and 11 by 3.4 mm and probably belong to the first and third digits respectively (see Plate 12: N-P).

The pelvis is represented by fragments of both ilia and ischia and nearly complete pubes (Plate 12: K and M). The left ilium consists of the anterior process, the pubic

TABLE 1. Comparative dimensions of *Microvenator* and some selected theropods.

	Microvenator celer AMNH 3041	*Deinonychus antirrhopus* AMNH 3015	*Coelurus agilis* YPM 2010	*Compsognathus longipes* (Cast, YPM 1472)	*Struthiomimus altus* AMNH 4339	*Ornitholestes hermanni* AMNH 619
Length of humerus	81.5	227	116	34a	310	127
Width across deltopectoral crest	21	43.5	20	—	—	—
Width of distal end	13	42	26	—	—	—
Least diameter of shaft	6	18	9	—	—	—
Length of ulna	78	186	95	28a	230	—
Width of distal end	9.5	28.3	11.3	—	—	—
Least diameter of shaft	3.4	11.8	4.8	—	—	—
Length of radius	75.6	172	78+	24a	—	—
Width of distal end	—	23.8	11	—	—	—
Least diameter of shaft	3.4	8.7	5	—	—	—
Length of femur	124	—	220±	69a	480	207
Width of distal end	24	—	45±	—	—	—
Proximal width	27	—	44.5	—	—	—
Least diameter of shaft	10.5	—	17	—	—	—
Length of tibia	157	324	255+	86a	540	159
Width of distal end	22.3	63.3	42+	—	—	—
Least diameter of shaft	8.0	18	17	—	—	—
Astragalus width	22.3	62	—	—	—	—
Astragalus height	29.0	77	—	—	—	—
Length of metacarpal I	17.6	43.2	—	—	85	—
Length of phalanx II-2	34.0	76.5	—	14.0a	90	—
Length of largest claw	25.0	95+	—	11.4a	85	—

Measurements in millimeters
a = approximate

and ischiac peduncles and the acetabular border. The major part of the iliac blade and posterior process are missing. The right ilium is represented only by the pubic peduncle and part of the anterior process. The latter is relatively short and deep and extremely thin. A thin medial ridge extends dorsoanteriorly along the internal surface from the pubic peduncle. A rugose scar occurs just above the latter marking the point of contact with the first sacral rib. The peduncles are quite robust considering the millimeter or less thickness of the iliac blade. The upper margin of the acetabulum is thickened (7 mm or more), reaching a maximum thickness midway between the pubic peduncle and the midpoint of the iliac acetabular margin, which suggests that the principal weight-bearing axis from femur to ilium was oblique to the long axis of the ilium.

The ischia are represented by the pubic peduncle of the right ischium and a midshaft section of the left, neither of which provides much information as to the size and form of these bones. The latter indicates a bladelike form measuring 8 mm wide and 3 mm thick. The pubes have robust proximal ends for junction with the ilia and stout, slightly curved, rodlike shafts that are transversely expanded in their distal halves. Distally, the pubes are expanded in the parasagittal dimension, both vertically and longitudinally, although they do not appear to have been expanded to the extent seen in *Ornithomimus altus* (AMNH 5339) or *Coelurus agilis* (YPM 2010). Length of the pubis is approximately 118 mm.

Both femora are well preserved and undistorted (Plate 13: A and B). Both show moderate curvature and subcylindrical shafts of 10 mm minimum diameter. The head is subspherical and sharply offset from the shaft. A prominent greater trochanter extends slightly above the head and is widely separated from the latter by a deep notch. A short lesser trochanter projects posterolaterally as a sharply defined crest well below the summit of the greater trochanter. The lesser trochanter is more prominent than in any other theropod with which I am familiar. The fourth trochanter is absent; in its place is a distinct, elongate, oval depression well below the head on the inner posterior aspect of the shaft. Distally the femur expands into two distinct, convex condyles of subequal size separated by a broad, deep groove. The two femora are much shorter than the tibia, measuring 124 and 122.5 mm compared with 157 mm for the left tibia.

The tibia is a long, straight-shafted bone apparently oval in cross-section. The proximal end is expanded anteroposteriorly and distally it is expanded transversely. A conspicuous, thin cnemial crest projects laterally about one fourth of the way down the shaft. Only the expanded proximal end of the left fibula is preserved. The fibula may have been incomplete in life, limited to just a proximal head and tapered shaft less than one third of tibia length. This is suggested by the delicate nature of the thinly tapered incomplete extremity of the fibula fragment, plus the absence of any appositional scar for the fibula along the distal external surfaces of the tibia (Plate 13: C, D and E).

The astragalus extends the full width of the tibial distal extremity with only a small recess marking the site of a minute chiplike calcaneum. The calcaneum itself is missing, but any contact with the fibula appears to have been weak. The ascending astragalar process is incomplete, but that portion preserved rises more than 27 mm above the distal astragalus surface, and appears to be a relatively much longer process than is characteristic of other theropods.

DISCUSSION: *Microvenator* was about the size of a small turkey, approximately twice the size of *Compsognathus*. It is one of the smallest known theropods. The possibility exists that the remains are those of a juvenile, but the preserved bones are all well formed, and in my opinion are those of an adult individual. Many of the sutures between neural arches and centra had not fused, but some in the caudal series and posterior dorsals appear to be closed. However, I am not convinced that open vertebral sutures have any ontogenetic significance.

Microvenator is distinct from *Segisaurus* in its hollow limb bones and vertebrae, from hallopids in its large manus and the absence of cervical spines, and from podokesaurids by the long ascending astragalar process. The remains resemble most closely those of *Coelurus* and *Ornitholestes*, particularly in the hollow, thin-walled and sculptured construction of cervical and dorsal vertebrae. They differ from *Coelurus* and *Ornitholestes*, though, in the form of dorsal and cervical neural arches, the absence of cervical neural spines and the moderate expansion of the distal end of the pubis. *Microvenator* resembles *Compsognathus* in the femur-tibia ratio, the lack of neural cervical spines and in the form of the manus unguals, but the fore limb of *Microvenator* is relatively much longer—almost equal to tibia length as in *Struthiomimus altus* (= *Ornithomimus*)—compared to the short (75% of tibia length) fore limb of *Compsognathus.*

Microvenator may be distinguished from the dromaeosaurids in the form and greater relative lengths of cervical and dorsal vertebrae, the much smaller internal tuberosity of the humerus, the long ascending process of the astragalus, the elongated, rodlike form of the pubes and the morphology of the manus, particularly the first metacarpal and unguals. Accordingly *Microvenator* seems most closely allied with *Compsognathus, Ornitholestes* and *Coelurus* and is placed in the Coeluridae.

Associated with the type specimen were 25 teeth of the *Deinonychus* type which Barnum Brown believed belonged to this specimen. There has been doubt in some minds that the teeth belong to the same individual because they are three to four times the size expected in an animal of these dimensions. Because of the extraordinarily large size of the associated teeth, this specimen has been known informally in conversation by the name "*Megadontosaurus*". Without exception, the 25 associated teeth duplicate in size and form the teeth found with the type of *Deinonychus antirrhopus.* The most significant character, however, is the pronounced discrepancy in the size of anterior and posterior tooth serrations, a trait that currently is known only in *Deinonychus* and *Velociraptor.* Conclusive evidence is not available, but on the basis of tooth form which is identical to that of another clearly distinguishable contemporary species, plus the high improbability of such relatively enormous teeth occurring in such a small animal, I here refer these teeth to *Deinonychus antirrhopus.* At present, however, they are still catalogued with the *Microvenator* remains under AMNH 3041.

Suborder SAUROPODOMORPHA

Infraorder SAUROPODA

The present state of sauropod systematics is one of disorder and confusion—to put it mildly. The reasons are rather obvious. The materials are large and difficult to handle, there are very few complete specimens and the great majority of species have been founded on incomplete and nondiagnostic fragments. A critical, modern revision is sorely needed, but it seems unlikely that one will be forthcoming in the near future. Recent practice has been to divide the Sauropoda into two family groups (Bothrosauropodidae and Homalosauropodidae of von Huene [1956]; or Brachiosauridae and Titanosauridae of Romer [1956]) or simply to recognize some six or eight categories of equivalent rank as Lapparent and Lavocat (1955) did. Because most of the taxa referred to any of these categories are based on fragmentary material, few are firmly established and the suprageneric categories are rather loosely defined. Accordingly, the fragmentary Cloverly sauropod remains are only tentatively assigned.

Isolated sauropod teeth, limb bones and vertebral fragments were found at a number of sites, but the most important collections were made at three Yale quarries (YPM 63-16, 63-18, and 63-19) near Crooked Creek, Wyoming. YPM 63-18 produced a number of limb and pelvic elements and seven vertebrae that were closely associated and these are presumed to be from a single individual (YPM 5449) and are described first. All other sauropod remains were sufficiently isolated from other sauropod elements within and between various quarries that they have been treated independently and catalogued as separate specimens. These last materials are described separately.

?FAMILY TITANOSAURIDAE Lydekker, 1893

Plate 13: F and G; Plate 14: A-D and F-H

REFERRED SPECIMENS: YPM 4888, 5103, 5104, 5107, 5116, 5147, 5151, 5152, 5116, isolated vertebrae; YPM 5449, associated vertebrae, limb and pelvic elements; YPM 5329, 5450, 5451, 5452, isolated limb bones; YPM 5347, 5349, 5360, 5365, 5374, 5375, 5419, 5453, 5454, 5455, isolated teeth. AMNH 3042.

LOCALITIES: YPM 62-10, 62-14, 63-16, 63-18, 63-19, 64-3, 64-39. AMNH 33-2.

HORIZONS: Units V, VI and VII, Cloverly Formation.

DESCRIPTION: YPM 5449—The items catalogued under YPM 5449 include the only closely associated sauropod material collected by Yale personnel from the Cloverly Formation and, because it includes vertebral and appendicular elements, it is the most important of the referred material and is described first. The possibility exists that these bones do not all belong to the same individual, but they were so closely associated—in some instances in contact—that this seems a remote possibility. The additional fact that all seven vertebrae are dorsals and were associated with two ischia and an ulna strengthens the supposition. All of the materials are distorted and incomplete; consequently, dimensions listed are only approximate and the following descriptions are based on several vertebrae.

Dorsal vertebrae. Two distinctly different types of vertebrae are present in YPM 5449; these are interpreted here as anterior and posterior dorsals (Plate 13: F and G). Both are strongly opisthocoelous and neither seems to have a divided or double neural spine. The anterior dorsals are characterized by large centra that are constricted at midlength laterally and ventrally, centra width is greater than centra height or length, and the zygapophyseal facets are far apart and lack hyposphene-hypantrum. The lateral surfaces are marked by small, deep, oval cavities or pleurocoels. The neural spine rises vertically as a single, robust, transversely expanded blade. Although none are complete, there is no evidence that any of the neural spines were divided. The transverse processes or diapophyses extend laterally and slightly upward as vertically expanded blades. The proximal parts of these are moderately excavated ventrally, posteriorly and anteriorly. On one of these anterior dorsals the parapophyses occur on the centrum, and this presumably is one of the first three dorsals. A second anterior dorsal lacks most of the centrum and the third shows no sign of the parapophysis either on the centrum or on the arch.

The four posterior dorsals, which were closely associated with the dorsals described above, are also strongly opisthocoelous and have large, oval pleurocoels high on the lateral walls of the centra. The centra are nearly circular in end view and 50 to 80 percent longer than the greatest diameter. A surprising feature is that the greatest diameters of the centra are significantly less than those of the associated anterior centra, a condition that has not been reported in any other sauropod. Although distorted and incomplete, the zygapophyseal facets are close to the midline and appear to have been oriented at about 45°. Two of the vertebrae show remnants of what I presume to be the hyposphene. None of the neural spines are well preserved, but they also appear to have been undivided and expanded longitudinally as well as transversely. Two vertebrae clearly show the neural spine inclined backward at about 30° to the vertical, but this may be the result of distortion. The neural arches are long and rather high and the pedicels are deeply excavated laterally by three complex cavities. Above the diapophysis, the base of the neural spine is similarly excavated by two deep and complex cavities. The excavations are generally similar in position and shape to those described in *Camarasaurus*, *Apatosaurus*, *Diplodocus* and others, but differ in details. Osborn's terminology may be applied to these excavations (infraprezygapophyseal cavity, infradiapophyseal cavity, and infrapostzygapophyseal cavity for those on the neural arch pedicels, and supraprezygapophyseal cavity and suprapostzygapophyseal cavity for those on the neural spine). These cavities are separated by prominent bony struts or lamina to which Osborn applied specific terms (i.e., infradiapophyseal lamina). The present material does not permit close detailed comparison of neural arch structure with other described material. However, within at least some of the neural arch excavations, there are complex "sub-cavities" separated by very delicate laminae.

The diapophyses are not complete in any of the present vertebrae, but they may have been shorter and more steeply inclined than those of the anterior dorsals. A solitary vertebra (YPM 5147) from an adjacent quarry at YPM 63-19, approximately 8 meters distant, corresponds to the last described vertebra in all respects, except that the centrum is longer relative to width or height, and the neural arch appears to be correspondingly elongated. The great length of the centrum is reminiscent of cervical vertebrae. Precise dimensions are not available due to the distorted and incomplete condition of this vertebra, and the parapophyseal region is incomplete. However, the great height of the neural arch and the close spacing of the zygapophyseal facets indicate this to be a posterior dorsal, rather than a cervical, but exactly which segment is not known.

Although smaller than those of most well-known sauropod species, the present vertebrae appear to be more extensively excavated than most, and on this character alone would seem to be excluded from the Cetiosauridae. Most significant of all, however, is the solitary or undivided form of the neural spine, especially of the anterior dorsals. Double, or split, neural spines are characteristic of the cervical and anterior dorsal

TABLE 2. Approximate dimensions of sauropod dorsal vertebrae (in centimeters).

	YPM 5449 Vertebrae*						YPM 5147
	A	B	C	D	E	F	
Greatest centrum width	20	—	22±	13±	17.5	10±	—
Greatest centrum height	13	—	14.5	14±	16.5	10	17.5
Greatest centrum length	13	—	16±	18.5	12?	19	28
Height of articular facets above centrum	10	12±	11	11.5	8.5	9	28±
Tranverse separation of zygapophyseal facets	6±	9	12	2±	1±	—	2
Greatest width of zygapophyseal facets	17±	18±	24	9±	13	—	13
Greatest width of diapophyses	64±	54	60±	—	—	—	—
Minimum tranverse width of neural spine	—	8.5	—	—	—	—	—
Neural spine height above neural canal	—	49+	—	34+	—	—	—

*The exact segment number is indeterminate. Consequently, the various vertebrae have been designated by letter.

vertebrae of all sauropods except the Brachiosauridae and the Titanosauridae. The present vertebrae differ from both brachiosaurid and titanosaurid vertebrae in the greater diameter and length of anterior dorsal centra relative to posterior dorsal centra. They also differ in the presence of a large triangular infradiapophyseal cavity in the neural arches of posterior dorsals. C. C. Young (1935) illustrated a series of posterior dorsal vertebrae of *Euhelopus* (= *Helopus*) from China in which there appear to be large triangular excavations beneath the diapophyses and above and between the infraprezygapophyseal and infrapostzygaphyseal cavities. Young did not identify or comment on the excavations, but this is the only sauropod material that I have been able to discover that corresponds to the Cloverly specimens in this particular character.

Ischium. Closely associated with the above vertebrae were incomplete left and right ischia, both of which lack the proximal portion. The ischium is a moderate-sized bone with a broad, nearly parallel-edged blade that is expanded slightly transversely and longitudinally at the extremity. The greatest preserved length is about 74 cm with perhaps 10 or 15 cm missing from the proximal region. The narrowest part of the blade measures about 15 cm by 4.5 cm in thickness at about midlength. The distal extremity is slightly expanded to a breadth of 23 cm and a thickness of approximately 6 cm. The greatest proximal dimension is not known, nor is the nature or orientation of the iliac peduncle.

The ischia are too incomplete to permit meaningful comparison with published illustrations. They differ significantly, however, from the co-ossified ischia of *Alamosaurus sanjuanensis* (Gilmore, 1946), perhaps the best known North American Cretaceous titanosaurid (Fig. 7).

Sternal bone. An incomplete, thin plate of bone, suboval in shape and measuring 39 by 27 cm, was found directly beneath the left ischium. It has been catalogued with the latter as YPM 5449 and referred to the previously described vertebrae. The identity of this bone is questionable, but it clearly is not part of either ischium or part of the pubis or ilium. The margins are preserved on two sides and one end, and the shape of this portion corresponds very closely to the anterior half of a right sternal bone, particularly that referred to *Apatosaurus excelsus* (YPM 1980) by Ostrom and McIntosh (1966). It is less robust than that element and approximately four fifths as large. This bone is very different from the sternal bones of *Alamosaurus* which have a strongly concave external margin.

Ulna. A left ulna was recovered close to the right ischium and is presumed to belong to the same individual. Although somewhat distorted by crushing, it is almost complete and provides a reasonably close approximation to the original form. It is straight and of rather slender proportions, measuring 60 cm in length, 26.5 cm in greatest proximal width, 12 cm in distal width and 26.5 cm in minimum girth of the shaft (Plate 14: D).

The ulna tapers gradually away from the proximal end, with the least diameter just below midlength. The proximal flanges are well developed and broadly rounded, the internal flange being the largest. These are separated by a rather deep radial concavity.

The relatively slender proportions of the ulna are similar to those in *Diplodocus* or *Brachiosaurus*, although the ulna of the latter is much longer relative to ischium length than in the present specimen. This slenderness is in sharp contrast to the short massive proportions in *Camarasaurus* and *Apatosaurus.*

DISCUSSION: Definitive evidence is not available for confident assignment of these remains. The dorsal vertebrae are consistent with both titanosaurids and brachiosaurids, but the distinctive features of these two groups are in the cranial and appen-

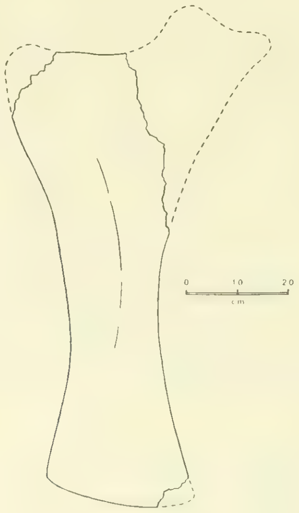

FIG. 7. Outline of sauropod ischium associated with dorsal vertebrae of Plate 12.

TABLE 3. Dimensions (in centimeters) of sauropod caudal vertebrae.

	YPM 5147	YPM 5199	YPM 5104	YPM 5103	YPM 4888
Centrum length	21 (= 2 vertebrae)	12	10	10	10
Centrum height	17.5 and 15.5	14	11	8	8±
Centrum width	25 and 21	18±	15.3	9.5	8
Total height	29.5 and 29	—	—	—	—

dicular skeleton. The relatively thin, unexpanded ischium and the slender, but not elongated ulna suggest titanosaurid rather than brachiosaurid affinities and I have therefore tentatively referred YPM 5449 to the Titanosauridae.

DESCRIPTION OF ADDITIONAL REFERRED MATERIAL: *Vertebrae.* A number of caudal vertebrae were recovered from several sites, including both proximal and distal segments. All are amphiplatyan and none possess pleurocoels. A distal caudal (YPM 5152) and a proximal caudal (YPM 5116) were collected at Yale locality 63-18, and a pair of co-ossified anterior caudals (YPM 5147) came from YPM locality 63-19. Two isolated anterior caudals(YPM 5199, 5104) from the latter quarry represent elements from between the fourth and tenth caudal segments, judging from the caudals of *Camarasaurus.* Each of these latter bones has short, low and broad centra, oval in end view, and slightly constricted in lateral and ventral surfaces. Short, robust transverse processes project out and backward, slightly inclined to the horizontal in the most anterior elements, and nearly horizontally in the two smaller vertebrae. The neural arch is very low and is topped by a very short, robust, and rugose neural spine. The neural arches are situated on the anterior halves of the centra and the prezygapophyses project well forward of the anterior face of the centrum. Distinct articular facets for the chevron are present posteriorly on the ventral surface of the two smaller vertebrae but not anteriorly. The two co-ossified caudals do not have chevron facets, indicating that these may represent the first two caudal segments.

Two distal caudals (YPM 5103, 4888) are known. They show no evidence of transverse processes, but both have low neural arches rising from the anterior half of the centrum. The centrum length is greater than width or height. The centra are constricted in lateral and ventral surfaces at midlength. No pleurocoels are present and the chevron articular facets are faintly evident at the posterior centrum margin.

These vertebrae differ from other sauropod caudals in several features. The amphiplatyan, transverse oval centrum face is characteristic of *Diplodocus*, but the high and robust neural arch at midlength of the centrum, with the downward-directed transverse processes, exclude this genus. High neural arches and spines, circular centrum faces and pronounced chevron facets, anteriorly placed as well as posteriorly, distinguish caudals of *Camarasaurus, Apatosaurus, Haplocanthosaurus* and *Brachiosaurus. Alamosaurus* caudals are strongly procoelous, but the anterior position of the neural arch and the forward extension of the prezygapophyses resemble the present vertebrae. The closest resemblance I have been able to discover is a vertebra figured by Owen (1859: Pl. X) as *Cetiosaurus brevis*—a sauropod proximal caudal from the Wealden of Sussex, England.

Questionable sauropod vertebra. When first exposed in the quarry at YPM 63-18, specimen YPM 5294 was thought to be a limb bone, but it proved to be a vertebral centrum of unusual proportions (Plate 15: A, B). The present length of 47 cm may be slightly less than the original length, but the greatest diameter (12 cm) is probably several centimeters greater than the original width. I would estimate the original maximum width at about 9 centimeters and maximum height about the same.

Although crushed the centrum appears to have been broadest at the ends and narrow near midlength. It is a strongly opisthocoelous (or procoelous?), and has long (20 cm or more), narrow and deep pleurocoels situated near midlength. The ventral surface appears to have been flat, or perhaps slightly concave in the anterior(?) third. The neural arch is missing, but broad sutural tracts are preserved on both sides of the 2 to 4 cm wide neural canal. These sutures extend nearly the full length of the centrum.

The inferior lateral surfaces of the anterior(?) half (if the centrum is opisthocoelous) bear thin, but long (anteroposteriorly) ridges, which extend laterally an unknown distance. The extremities of the lateral ridges are missing so the transverse dimensions are not known, nor is their original attitude preserved. These ridges would appear to be the basal or proximal portions of thin parapophyseal laminae. If so, then this centrum would appear to be a cervical vertebra. Without the distal extremities of these lateral ridges or the neural arch, no conclusion can be made, but the ridges are remarkably thin (dorsoventrally), and I am not at all certain that they bore cervical ribs.

Although very different in its proportions, this centrum is best referred to the Sauropoda on the grounds that it is apparently opisthocoelous, it bears long pleurocoels and is greatly elongated, as are many sauropod cervicals. If correctly interpreted as a cervical, it most closely resembles the midcervicals of *Diplodocus* or *Brachiosaurus* in its proportions, as the following ratios show:

	Posterior Maximum Diameter/Length
YPM 5294	0.25
Diplodocus	0.21
Brachiosaurus	0.27

However, the parapophyseal lamina is much more robust and not so elongated in these two genera, and the pleurocoels are of more complex construction.

Despite its unusually narrow construction, this vertebra is of appropriate size for equating with the dorsal vertebrae (YPM 5449) described above from the same quarry (YPM 63-18). Because of its widely separated position in the quarry, though, and its incompleteness, I am not able to certify the relationship.

Limb elements. An isolated femur, tibia, and humerus were collected at three adjacent Yale sites (Plate 14: A-C). These cannot be referred with certainty to the previous material, but there is a distinct possibility that all the remains represent a single species. The femur (YPM 5451), a right, from Yale locality 63-18, is very large but relatively slender. It is crushed and the proximal end is missing, but original length must have been at least 1.5 meters. The preserved length is 126 cm, but the fourth trochanter which is normally at midlength is 80 cm from the distal end. The crushed, maximum proximal width is about 40 cm, approximately 40 cm above the very small fourth trochanter. The greatest transverse, distal dimension is approximately 39 cm and the tibial or inner condyle is 20 cm in longitudinal dimension. The least breadth of the shaft is 22 cm and the circumference at that point is 52 cm.

The tibia (YPM 5450), a left, from Yale locality 63-19, is also slightly crushed but otherwise intact. There is a deep external excavation proximally for the fibula, with a short, rounded cnemial crest descending for a short distance along the shaft. Both the proximal end and the two condyles distally are moderately to strongly rugose. The dimensions are as follows:

Length	98.5 cm
Greatest proximal width	24 cm
Distal transverse width	21 cm
Least shaft width	13 cm
Least circumference	32 cm

The humerus (YPM 5452), a right, from Yale locality 63-16, lacks the distal end, but in general it is rather brachiosaur-like. The proximal end is greatly expanded (43 cm) compared with a midshaft diameter of 20.5 cm. The preserved length is 103 cm, but the original length may have been as great as 130 cm. This estimate is based on the position of the very prominent deltopectoral crest that extends almost 50 cm below the proximal head, and the distal limit of the deltopectoral crest in *Brachiosaurus* (approximately 38% of humerus length). The analogy with this genus is based on the very broad nature of the proximal end, the long and relatively slender shaft, the nearly straight external margin and the fact that the deltopectoral crest is not a continuous ridge extending from the proximal end, but is a restricted projection. The least circumference of the shaft is approximately 51 cm.

Teeth. A total of 13 isolated teeth were recovered from several of the Yale localities. All are of one kind, which is best described as nonspatulate, *Pleurocoelus* or *Astrodon* type. Within the collection there is a considerable range in size, but very little variation in tooth form. The root is long, cylindrical and untapered and of about the same diameter as the crown; the crown is subcylindrical, being slightly flattened on one side (the inner side?) and more convex on the other. In some specimens these opposite surfaces extend straight to the bluntly tapered apex, but in others they are slightly twisted so that in crown view the entire crown appears twisted. The crown also tapers asymmetrically so the apex lies closer to one margin (the anterior?) than the other. The enamel is faintly wrinkled on unworn teeth, but there are no serrations or rugae along the two vertical ridges that separate labial and lingual surfaces of the crown. There is moderate variation in the degree of asymmetry. In some crowns the apex is near the tooth central axis and there is little or no twisting. Most teeth are nearly straight, with almost no lingual curve to the crown. A few, however, show a pronounced medial curvature of the crown. The roots are never complete, but the crown height appears to be quite constant relative to the basal crown's least diameter, with the height almost exactly four times that diameter. The largest tooth measured 28 mm in crown height by 7 mm in least diameter. The smallest is 11 mm long by 3.8 mm basal diameter.

The striking similarity of these teeth to the type of *Astrodon johnstoni* (YPM 798) and the numerous teeth referred to *Pleurocoelus* from the Arundel Formation of Maryland is evident in Plate 14. *Astrodon* is slightly larger (40 mm high and 10.3 mm in basal diameter) than the largest tooth from the Cloverly Formation, and the crown is somewhat less convex on the lingual side and curves inward more than any of the Cloverly teeth. Otherwise the resemblances are very close. Although there seems to be a little more variation of tooth morphology in the somewhat larger Arundel sample, the majority are small (under 20 mm in crown height), not strongly curved and not markedly asymmetrical—as is true of the Cloverly sample. The range of variation in the ratio of crown height to basal crown diameter is the same for both samples (0.24 to 0.29) with most teeth having a ratio of 0.25 or 0.26.

The absence of large spatulate *Camarasaurus*-type teeth in the Cloverly is not conclusive, but it is quite probable that the *Astrodon*-type teeth and the various postcranial sauropod remains represent a single species. This is reinforced by the fact that several of these teeth were found at Yale locality 63-18, associated with postcranial remains described above.

DISCUSSION: The first notice of the distinctive tooth type described above was by a Dr. Christopher Johnston (1859), who referred to a reptilian tooth from an iron ore bed (Arundel Formation) near Bladensburg, Maryland. He gave it the name *Astrodon* but did not describe it. Leidy (1865) described the tooth as *Astrodon johnstoni*, referring it to the Sauropoda. Subsequently Marsh (1888) established two other Arundel species of sauropod (*Pleurocoelus nanus* and *Pleurocoelus altus*) on isolated postcranial elements. Hatcher (1903) synonymized *Pleurocoelus nanus* (a cervical centrum) with *Astrodon johnstoni*, and Gilmore (1921) assigned all the Arundel sauropod remains to the genus *Astrodon*. Lull (1911a) recognized the probable synonymy of *Astrodon* and *Pleurocoelus*, but rather than equating *P. nanus* and *A. johnstoni* he suggested that *P. altus* (a tibia and partial fibula) was synonymous with *A. johnstoni*. He concluded: "It seems preferable, however, in view of the rarity of the remains to let the matter rest in abeyance until further proof is obtained." Further proof has not been obtained, the question is still unresolved, and I suspect it will always be so.

Sauropod teeth seem to be of two general types, large spatulate and small, cylindrical, nonspatulate form. There is some variation in each, both in size and in form, even within a single individual. At present, though, there seems to be no reliable means of identifying specific or even generic taxa from isolated teeth. The large spatulate *Camarasaurus*-type teeth have relatively short crowns (ratio of crown height to basal crown diameter ranges from 0.30 to 0.42, with the mean approximately 0.36), and the crown is significantly broader (longitudinally) than the root. The lingual crown face is planar or moderately concave, and the unworn apex or crest is broadly rounded rather than tapered. Such features are distinct from those of an *Astrodon*-type tooth, but are these differences ontogenetic or taxonomic? Is the *Astrodon* or *Pleurocoelus*-type tooth merely a juvenile or immature stage in the development of the spatulate *Camarasaurus* tooth? The absence of any of the latter teeth in the Arundel, Cloverly or Wealden Formations, which have produced numerous examples of *Astrodon* or *Pleurocoelus*-type teeth, would seem to suggest a taxonomic distinction, but indisputable evidence is still wanting.

I am inclined to agree with Hatcher, Lull and Gilmore on the probable relationships of sauropod teeth and postcranial elements from the Arundel Formation. I think the same may be true of the sauropod materials from the Cloverly Formation. However, in the absence of any conclusive evidence, I consider the name *Astrodon john-*

stoni as applicable only to the type specimen and similar teeth from the Arundel Formation, and *Pleurocoelus nanus* and *P. altus* as pertaining to certain postcranial remains from the same unit. The Cloverly sauropod remains are for the most part isolated and inadequate for the foundation of specific taxa. Vertebral and dental morphology indicate that these materials are best referred to Titanosauridae.

In 1917, Mook described a partial skeleton (AMNH 5855) that he referred to *Diplodocus*. This specimen, consisting of nearly complete fore and hind limbs lacking the feet, had been collected by Barnum Brown in 1903 "at Horse Coulée 30 miles [48 km] east of Pryor, Montana." No other locality or stratigraphic data are available, but the fact that these represent the most complete sauropod remains known from within the study area warrants some comment here. A specific identification is not possible, but I believe the reference to *Diplodocus* is correct. The limb proportions compare well with those of other *Diplodocus* specimens and the oblique orientation of the transverse scapular expansion is unique to that genus. Each limb element is significantly smaller than that in any of the Yale specimens, and the proportions do not compare closely with the latter. Photographs on file at the American Museum show the specimen *in situ*, but I was unable to relocate the site from these. However, I suspect that the specimen was recovered from Unit III (Morrison Formation) and not from the Cloverly Formation. Extensive exposures of Unit III occur in the area of Horse Coulée southwest of the Yale localities (Locality Map V) and the terrain there corresponds in a general way with that shown in the American Museum photographs.

ORDER ORNITHISCHIA
SUBORDER ORNITHOPODA

FAMILY IGUANODONTIDAE Marsh, 1895

Tenontosaurus, new genus

ETYMOLOGY: *Tenon* (Greek; masculine), sinew, in reference to ossified tendons along the vertebral column, and *sauros* (Greek; masculine), lizard.

TYPE SPECIES: *Tenontosaurus tilletti*, new species.

DIAGNOSIS: Same as that of the type and only species.

Tenontosaurus tilletti, new species
Plates 16, 17, 18, 19, 20 and 21

ETYMOLOGY: *Tenontosaurus tilletti*; named for the Lloyd Tillett family of Lovell, Wyoming, to whom we are indebted for assistance and hospitality extended to our field parties.

TYPE SPECIMEN: AMNH 3040, a partial skeleton, lacking skull and fore limbs.

PARATYPES: PU 16338, a partial skeleton; YPM 5456, fine skull and partial skeleton.

TYPE LOCALITY: AMNH 33-1, SW ¼ Sec. 26, T.7 N., R.16 E., Wheatland County, Montana. Unit VII, 60 feet (18 m) below Unit VIII, Cloverly Formation.

PARATYPE LOCALITIES: PU 48-1, T.6 N., R.15 or 16 E., Wheatland County, Montana (exact location and stratigraphic position unknown). YPM 64-37, NW ¼ Sec. 24, T.5 S., R.28 E., Big Horn County, Montana.

REFERRED SPECIMENS: Partial skeletons (YPM 5457, 5458, 5459, 5460, 5461, 5462, 5466, 5478; AMNH 3010, 3011, 3012, 3013, 3014, 3017, 3031, 3034, 3043, 3061, 3062, 3063; OU 11; PU 16514; and BB 1); skull and jaw fragments (YPM 5471, 5472; OU 8-0-52).

ADDITIONAL REFERRED SPECIMENS: YPM 4882, 5117, 5195, 5299, 5410, 5411, 5413, 5416, 5417, 5421, 5422, 5424, 5426, 5427, 5428, 5463, 5464, 5465, 5467, 5468, 5469, 5470, 5473, 5474, 5475, 5476, 5477, 5479, 5480, 5481, 5482, 5483, 5523, 5533, 5534, 5535; AMNH 3020, 3044, 3045, 3050, 5854; OU 12.

LOCALITIES: AMNH 03-29, 31-3, 31-4, 31-5, 31-6, 31-7, 31-8, 31-10, 32-2, 32-5, 33-3, 33-4, 33-5, 33-8, 38-1, 38-3, 38-4; OU 40-11, 40-12; PU 49-1; YPM 62-4, 62-14, 63-18, 64-13, 64-16, 64-17, 64-18, 64-19, 64-20, 64-21, 64-23, 64-25, 64-26, 64-27, 64-28, 64-36, 64-38, 64-39, 64-41, 64-43, 64-45, 64-47, 64-49, 64-50, 64-52, 64-54, 64-57, 64-58, 64-63, 64-64, 64-67, 64-71, 64-72, 64-74, 64-75, 65-1, 66-4.

DISTRIBUTION: Units V, VI and VII, Cloverly Formation, central and southern Montana and northern Wyoming.

DIAGNOSIS: Large, bipedal ornithopod with moderately deep, *Iguanodon*-like skull and extremely long tail reinforced by ossified tendons on either side of both neural spines and chevrons. Caudal series includes up to 60 vertebrae and measures twice (or more) the length of the precaudal column. Ischium long, straight; not expanded distally. Pubis with straight, shallow, parallel-sided and horizontal prepubic blade and long, straight, narrow postpubic rod. Ilium with long, narrow, sharply downturned anterior process and conspicuously concave upper margin. Pes with unreduced metatarsals I-IV, and splintlike V. Phalangeal formula 2-3-4-5-0. Manus very broad, with five flattened metacarpals. Phalangeal formula 2-3-3-2-2, digits IV and V lacking clawlike unguals. Vertebral count 12-16-5-59+. Skull with very large external nares, long slitlike antorbital fenestra and supplementary lateral temporal fenestra beneath the usual lateral fenestra. Orbit subrectangular; larger than either lateral fenestra. Premaxilla, which nearly encircles the nares, flares inferiorly into broad, U-shaped edentulous beak, opposed by shallow, horseshoe-shaped predentary with pseudo-tooth projections along upper margin. Mandibles bear two distinct coronoid processes and a long curved retroarticular process. Quadrate long, very narrow transversely; posterior margin convex rather than concave Paroccipital processes hook-shaped, and downturned at extremity. All teeth unilaterally enameled, dentary teeth with very prominent vertical keel, maxillary teeth without keels but with numerous nonparallel, subequal minor ridges.

DESCRIPTION: In the following pages an attempt is made to present sufficient description of the osteology of *Tenontosaurus* to define the taxon. A more detailed description is planned for the near future. The available collections of material referable to *T. tilletti* are extensive, making this perhaps the most abundantly represented fossil tetrapod at the time of its proposal. Twenty-six partial or nearly complete skeletons are known, eight of which are juvenile. Most of the others are mature but not fully grown. This sample provides an ususual opportunity to do a detailed analysis of variation and growth changes. The present report does not seem an appropriate place, however, and I defer this to a later contribution.

Skull. Several partial skulls are present in the collections of *Tenontosaurus*, but the best by far is the complete paratype skull YPM 5456 (Plate 16: A; Plate 17: A). In fact, this skull is probably the best skull in existence of a pre-Late Cretaceous ornithopod from the Western Hemisphere. The following description is based almost entirely on that specimen, with occasional comparisons with the sub-adult skull of YPM 5458 and several other fragmentary skulls. Some comparisons are made with skull fragments of *Camptosaurus* and the restorations of that genus given by Gilmore (1909), as well as with certain other ornithopods (*Laosaurus, Dryosaurus, Parksosaurus, Dysalotosaurus, Heterodontosaurus, Thescelosaurus* and *Iguanodon*).

In lateral view, the the skull is long and deep, in pronounced contrast to the low profile of *Camptosaurus* (Fig. 8). It has a large subrectangular orbit, a smaller oval lateral temporal fenestra and large external nares. A small oval subsidiary lateral temporal fenestra is situated between the jugal and quadratojugal near the lower margin of the lower temporal arch, and a long narrow slitlike antorbital fenestra descends obliquely across the maxilla from the lacrimal. The greatest skull length is approximately twice the skull height.

In dorsal aspect, the skull is narrowly wedge shaped with stout, rostrally rounded premaxillae and a sharply concave occipital outline. The greatest breadth is in the temporal region. The supratemporal fenestrae are oval and of moderate size.

The snout is dominated by the stout, edentulous premaxillae which flare out broadly below into a rounded, spatula-like beak. Dorsally, they extend backward as long, narrow, parallel-sided processes that interpose between the nasals for a distance of about 9 cm. This is well preserved in YPM 5456 and 5459. Similar interposition of

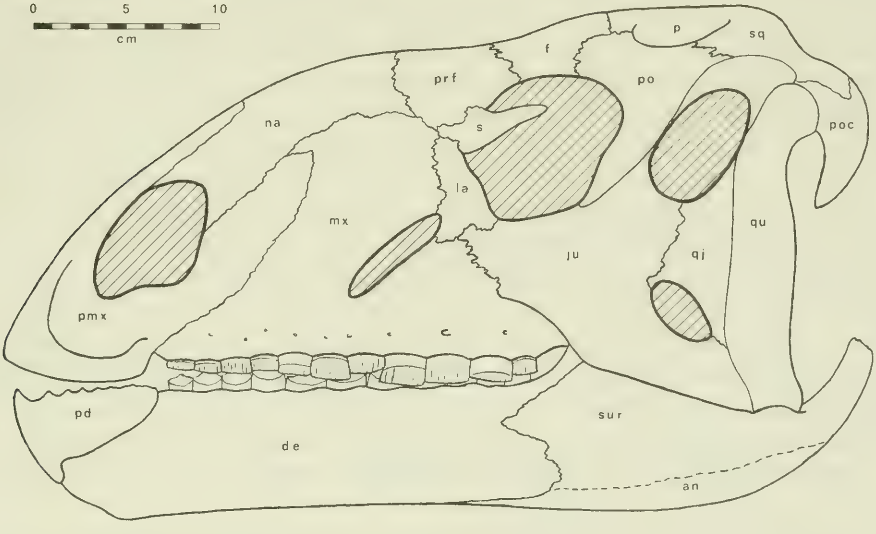

FIG. 8. Reconstructed lateral view of the skull and mandibles of *Tenontosaurus tilletti*. Abbreviations: an = angular; de = dentary; f = frontal; ju = jugal; la = lacrimal; mx = maxilla; na = nasal; p = parietal; pd = predentary; pmx = premaxilla; po = postorbital; poc = paroccipital process (exoccipital &/or opisthotic); prf = prefrontal; qj = quadratojugal; qu = quadrate; s = supraorbital; sq = squamosal; sur = surangular.

the premaxillae exists in *Hypsilophodon* (Galton, personal communication) but is not characteristic of *Heterodontosaurus* (Crompton, personal communication), *Camptosaurus, Iguanodon* or apparently of *Laosaurus.* This region is not known in *Thescelosaurus* or *Parksosaurus.* The premaxillary margins are moderately sharp edged with very small toothlike projections near the midline. In lateral view, the premaxilla is U-shaped with upper and lower processes projecting up and back, enclosing the external nares. Only the upper rear margin of the narial opening is formed by the nasal.

The maxilla is long and very high, accounting for the greatest fraction of snout depth. The maxilla apparently differs from that of *Camptosaurus* in that it extends all the way to the nasal lower margin and thus truncates the inferior premaxilla process and obstructs contact of the latter with any of the circumorbital elements. With the possible exception of *Heterodontosaurus* (and *Iguanodon atherfieldensis*?), contact of the maxilla and nasal appears to be true of all primitive ornithopods for which adequate material is available. It is quite likely that Gilmore (1909) and Marsh (1896a) erred in restoring the inferior premaxilla process of *Camptosaurus* as extending to the prefrontal and lacrimal.

A long (7 cm), narrow (1.5 cm), obliquely oriented antorbital fenestra extends down and forward from the lacrimal across the maxilla. The upper wall of this fenestra slopes inward and inferiorly and a robust ridge, the inner maxillary lamina, defines the lower medial fenestra margin. These do not meet, however, and the fissurelike opening extends medial to the maxilla into the nasal cavity. Thus this opening is properly termed an antorbital fenestra. I have no explanation for the function of this opening, but its conformation and position seem to preclude any relationship to the pterygoideus musculature, in spite of the fact that the ventral flange of the pterygoid is unusually large for an ornithopod.

The maxilla bears 13 alveoli, which are occupied by stout and unusually broad, unilaterally enameled teeth of the iguanodont type (see Plate 16: C-E). These are enameled laterally and bear five or six faint, subequal ridges, but lack a prominent keel as in *Camptosaurus* (Pl. 15: G) and *Iguanodon.* Unworn teeth are denticulate marginally; worn teeth develop internally inclined wear facets. No more than one functional tooth occurs in each alveolus. The tooth row length is approximately 18 cm with the anterior extremity situated exactly at the rear margin of the premaxillary beak.

The maxilla articulates posteriorly with a very deep triangular jugal, which is distinctive among all presently known ornithopods by its great depth. This bone is very robust dorsally where it joins the lacrimal and forms the stout lower margin of the orbit, but inferiorly the jugal is quite thin. The postorbital process is also robust and together with the descending process of the postorbital (postfrontal) forms a very massive arch between the orbit and the lateral fenestra. The jugal meets a subrectangular quadratojugal posteriorly, but inferiorly a posterior process extends back to the distal end of the quadrate. This process and the quadratojugal define the small auxiliary temporal fenestra, which appears to represent a true fenestra and not just an open suture.

The function of this latter opening is presumably related to the superficial external adductor muscles, in view of the fact that it is situated immediately lateral to the summit of the coronoid (not dentary) process of the mandible where it would have provided additional space for the bulging muscle belly.

The other bones surrounding the orbit are the robust lacrimal and prefrontal anteriorly and a narrow, wedge-shaped supraorbital, plus a lateral expansion of the frontal.

above. Small supraorbitals are preserved on both sides but these are depressed into the orbits. They appear to have been situated as restored by Gilmore (1909) for *Camptosaurus*, but of less robust form.

The quadrate is long, narrow and nearly straight. The posterior margin is convex rather than concave, although the upper end does hook slightly backward. The quadrate appears to have been vertical in orientation. Its dorsal extremity is rounded in lateral aspect, but narrow and tabular in transverse form, and fits into a shallow, rounded concavity in the squamosal. There may have been some mobility at this junction, but no other evidence of streptostyly is apparent. In YPM 5472 the proximal ends of both quadrates are in normal position with respect to the squamosals, despite considerable distortion and displacement of other skull elements, indicating a firm union of the two bones. The quadrate is extremely narrow transversely over most of its length but broadens out distally into a very robust (transversely) articular head. In anterior aspect, the quadrate appears to have had a short (anterposterior) but high superficial flange (articulating with the quadratojugal and jugal) and a long and high pterygoid flange that extended anteromedially. Both contributed to the posterior wall of the lateral temporal fenestra.

The dorsal aspect of the skull (Fig. 9), except for the beak, is formed by long, narrow, paired nasals, which pass between the prefrontals, the broad, very stout, paired and firmly united frontals, massive fused parietals and strongly convex, three-cornered squamosals. There is no sign of a sagittal crest across the parietals in YPM 5456 or 5472, but a slight crest occurs in OU 11 and BB 1. The greatest width of the frontals and parietals is approximately 50 to 60 percent of skull height.

The occipital surface is composed of the usual elements, but the triangular supraoccipital is excluded from the foramen magnum (OU 11 appears to be a possible exception, although preservation may account for this) and the basioccipital is almost excluded. The latter forms most of the occipital condyle, with the exoccipitals contributing only small wedges on either side of the neural canal. Large, hook-shaped, bladelike paroccipitals extend out, back and downward from the foramen magnum,

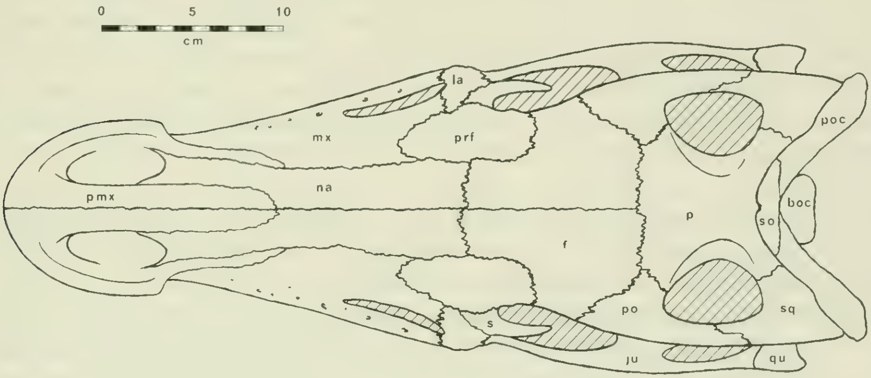

FIG. 9. Reconstructed dorsal view of the skull of *Tenontosaurus tilletti*.
Abbreviations: boc = basioccipital; f = frontal; ju = jugal; la = lacrimal; mx = maxilla; na = nasal; p = parietal; pmx = premaxilla; po = postorbital; poc = paroccipital process (exoccipital &/or opisthotic); prf = prefrontal; qu = quadrate; s = supraorbital; so = supraoccipital; sq = squamosal.

very similar to those of hadrosaurs. YPM 5456 and 5472 clearly show there is no dorsal expansion of these processes as in *Camptosaurus*, and they appear to be composed entirely of the exoccipitals.

The basicranium is greatly compressed longitudinally. The basisphenoid projects far ventrally as three massive processes. The laterally placed processes presumably represent the basisphenoid tubercles. Anterior, and slightly lateral to the latter are two very long subcylindrical basipterygoid processes that project far ventrally and slightly lateral to articulate with the broadly expanded pterygoids. The position of the braincase itself is rather high, and the greatly deepened skull has resulted in elongation of the quadrate and the basipterygoid processes. Thus the articulation of braincase (basisphenoid) and palatal complex (pterygoid) has been maintained but depressed to a very low position close to the level of the dentition. The distal extremity of the quadrate is situated well below the dentition as in all ornithopods.

The pterygoid ventral flange is a broad and deep, somewhat sinuous plate of bone. The upper portion may have provided enlarged and reinforced areas of origin for slips of the pterygoideus musculature. The broad, ventral part appears to have roofed over the posterior part of the oral cavity and formed a solid buttress between the caudal extremities of the maxillae. The ectopterygoid appears to have been reduced to a small slip of bone medial to the jugal and posterior to the maxilla, immediately behind the tooth row.

The anterior portion of the palate is largely obscured, but the palatines appear to extend forward from the ventral pterygoid flange to at least midlength of the maxillary tooth row—the apparent position of the internal nares. Rostral to this, details cannot be recognized at present, although there is a thin lamina of bone that underlaps the ventral surface of the premaxillae. This appears to be an inferior forward extension of the maxillae (which seems unlikely), but it probably is an anterior portion of the vomer.

The skull of *Tenontosaurus* resembles the skull of *Heterodontosaurus, Hypsilophodon, Laosaurus* and *Dryosaurus* in its deep, narrow form and the elongated and nearly vertical quadrate. *Camptosaurus*, on the other hand, has a very low, long and relatively broad skull, with a short, forwardly inclined quadrate. *Heterodontosaurus* and *Hypsilophodon* are distinct in having premaxillary teeth, as well very large orbits and small external nares. Both have moderate- to large-sized antorbital fenestrae, but of distinctive form. Similar openings apparently were present in *Laosaurus* and *Dryosaurus* where, like *Heterodontosaurus*, they were entirely within the maxilla. In *Hypsilophodon* this fenestra is bordered by the maxilla and the lacrimal, as it is in *Tenontosaurus.*

Hypsilophodon appears to be the only other ornithopod known in which a secondary or subsidiary lateral temporal fenestra occurs. In the British genus, however, it is situated within the quadratojugal, whereas in *Tenontosaurus* fenestration appears to have taken place along the quadratojugal–jugal suture. Of special interest, however, is the fact that in all other adequately known hypsilophodonts and iguanodonts (*Iguanodon* and possibly *Dryosaurus* excepted), there is a distinct to very prominent, ventroposteriorly directed bony process or boss on the inferior margin of the jugal arch. A narrow to broad notch or recess occurs between this and the lower part of the quadrate. It seems likely that the jugal fenestra (subsidiary lateral fenestra) may have been enclosed by extension of this jugal flange back to the quadrate. *Dryosaurus*(?)

and *Parksosaurus* lack both the jugal flange and the recess behind it. However, the *Parksosaurus* skull is incomplete in the upper temporal region, and it is conceivable that two lateral fenestra were present. There is no evidence for this, however.

The fact that the jugal of *Tenontosaurus* articulates with the quadrate below and behind this secondary fenestra, and not with the quadratojugal, is strong evidence that this is a secondary and perhaps specialized adaptation, conceivably to further buttress the quadrate close to the jaw articulation. This would suggest that the subsidiary fenestra is not due to a failure of the jugal-quadratojugal suture to close.

Mandible. The lower jaw of *Tenontosaurus* is of moderate length and robustness (Plate 16: B; Plate 17: B)). In lateral view it is straight, with parallel upper and lower margins, and of uniform depth anterior to the coronoid process. The two mandibles are closely appressed together in YPM 5456 so that very little of the medial aspect is visible. For this reason, the details of the postdentary and medial elements are not completely known.

The symphysis is capped by a median, horseshoe-shaped predentary of shallow depth that is remarkably similar to that of *Iguanodon* (Casier, 1960, Fig. 13). The two lateral rami rest in dorsally facing grooves along the upper anterior margins of the dentaries. These grooves appear to terminate immediately in front of the first tooth so that the tooth row is continuous with the upper margin of the predentary. This upper predentary margin is sharp crested and is decorated by small (posterior) to large (anterior) conical projections, like the predentary of *Iguanodon*. These projections may have served to unite firmly the predentary and a covering horny bill, or they may have served to reinforce similar projections along the margins of the horny beaks. A broad ventral process extends ventrally in the midline and overlaps the symphyseal region of the dentaries anteriorly.

The symphysis itself is not sutured and appears to have been rather flexible, restricted in mobility by the capping predentary and ligaments. The dentary is moderately massive and bears a long straight tooth row (17 cm) of 12 and 13 teeth. Posteriorly, the dentary expands upward into a short and relatively lightly constructed coronoid process, which is separated by a shallow notch from the lower, and broader bladelike "coronoid process" formed by the surangular.

Although the exact size and form is not known, the surangular appears to form most of the external surface of the mandible below and behind the coronoid process. In addition to the dorsal blade, it extends backward to the glenoid region and perhaps beyond. No suture has been recognized between it and the articular, so exactly what portions of the glenoid and retroarticular process are constructed of the surangular are not known. A large surangular foramen is present immediately anterior to the glenoid.

Part of the left angular is present, although displaced, but its exact relation to the surangular is indeterminate. A long splenial is partially visible along the inferior medial aspect of the right dentary, but its form and length are not known. The glenoid and retroarticular process are presumed to be composed chiefly of articular. The retroarticular process is quite long and bladelike, narrow transversely and broad vertically. It curves sharply upward behind the glenoid. The latter occurs as a broad, transverse concavity at the base of the surangular "coronoid process". In both rami, it is significantly narrower in its transverse dimension than is the distal head of the quadrate. This could mean that the medial portion of the glenoid has been displaced and the articular, or prearticular, is not preserved. Several bone fragments partly exposed between the two jaws could be parts of the prearticular, and I have so interpreted them. The articular, I believe, was fused with the surangular.

The mandibular teeth are of the iguanodont type, enameled on the medial side only (Plate 17: C, D and E). Most are large and oval in crown shape, with denticulate margins. The enameled surface bears a very prominent vertical ridge (unlike *Camptosaurus* mandibular teeth, Plate 15: F), on either side of which are several faint, subparallel ridges. Tooth-wear facets are inclined labially.

Associated with the jaws (and the right quadrate) are a number of subcylindrical bones, approximately 1 centimeter in maximum diameter, that are presumed to represent hyoid elements. These are too incomplete and poorly preserved to be identified further. A very small cylinder of bone is also preserved medial to the upper end of the right quadrate. This may represent part of the right stapes.

Vertebral column. The presacral vertebral count is 28, including 16 dorsals and 12 cervicals. The count is based on several specimens (OU 11, YPM 5459 and 5456, BB 1, and AMNH 3031). The sacrum consists of 5 segments, which may be augmented by a dorsosacral and/or a caudosacral. Where either of these is coalesced with the sacrum, they are counted here as dorsal or caudal vertebrae. The caudal series is extremely long, including 59 or 60 segments, and total tail length measures two or two and a half times the length of the sacrals and presacrals.

Camptosaurus, with which the present species can most adequately be compared, has 9 cervicals, 16 or 17 dorsals, 4 or 5 sacrals and approximately 44 caudals. There was some question about the vertebral formula in *Camptosaurus*, according to Gilmore (1909), but the articulated series of *C. medius* (CM 11,337) described by Gilmore (1925) established the presacral count at 9 cervicals and 17 dorsals. Gilmore recognized 5 sacral vertebrae in this specimen, but as he noted (1909, p. 235), the sacrum of *C. dispar* consists of only 4 vertebrae. Whatever the sacral count, *Camptosaurus* apparently had 26 presacrals compared with 28 in *Tenontosaurus*.

A complete caudal series is not known for *Camptosaurus*, but Gilmore (1909) estimated the caudal count at 44, on the basis of two nearly complete series of 33 and 34 segments (USNM 4282 and 2210). Including the 11 missing distal caudals and several missing presacrals in USNM 4282, the tail length of *Camptosaurus browni* would have been only slightly longer than the precaudal column.

The cervicals of *Tenontosaurus* (see Plate 18: A-D) are distinct in the low neural spine, low arch, and in the position of the parapophysis on the centrum. They compare closely with those of *Camptosaurus*, except in number. In general, the cervical centra are relatively shorter and slightly broader and deeper than those of *Camptosaurus*. They also tend to be amphiplatyan rather than opisthocoelous. All except the atlas and axis are moderately keeled ventrally and bear broad, low neural arches. In contrast to *Camptosaurus* where only faint ridges mark the cervical neural spines, the cervicals of *Tenontosaurus* bear short but well-developed neural spines on all segments. These are well preserved in YPM 5456. Also, contrary to the condition in *Camptosaurus*, the atlas centrum is significantly shorter than succeeding centra, but it carries a *Camptosaurus*-like arch bearing a high wedge-shaped neural spine with a broad, concave posterior surface. The atlas intercentrum, odontoid and axis intercentrum are represented in several specimens, and are similar to those of *Camptosaurus*. In OU 11, both the odontoid and axis intercentrum are fused to the axis centrum. In YPM 5456, which is the largest specimen presently known, the odontoid is not fused to the axis, but the axis intercentrum is. In BB 1, both elements are free and not coossified with the axis centrum. Despite Gilmore's statement to the contrary (1909, p. 225), the odontoid is coalesced with the axis in at least one specimen (YPM 1877) of *Camptosaurus*. The axis intercentrum apparently always is fused with the axis centrum in *Camptosaurus*.

The dorsal vertebrae (Plate 17: E-H) are well preserved in the type of *Tenontosaurus* (AMNH 3040) and the paratype (PU 16338). Again these vertebrae are rather similar to those of *Camptosaurus*, but differ in having relatively shorter centra with much shorter and narrower neural spines and transverse processes. Also, the neural spines are more rounded or less rectangular in profile. All centra are amphiplatyan and subcircular in anterior or posterior view. The neural arches are firmly sutured to the centra in sub-adult specimens, but the sutures apparently remained open even in the largest individuals, as is evidenced by several separated centra and the arches in YPM 5456. The neural arches are low and robust and the zygapophyses quite short with facets inclined at about 45° throughout the series. The parapophysis and diapophysis are widely separated on the first 12 dorsals but are closely spaced on the thirteenth. The last three dorsals have a common articular facet for the capitulum and tuberculum at the extremity of the transverse process, and in at least some instances the single-headed rib is fused to that process. The sixteenth dorsal, with the transverse process and rib contacting the anterior blade of the ilium, also supports the anterior part of the first sacral rib borne on the following sacral. The sacral count is dependent on distinguishing between true sacrals and coalesced dorsosacrals or caudosacrals. I have defined the first sacral as the first vertebra bearing a lateral process (transverse process) that is not borne entirely on the neural arch. The last sacral vertebra is the most posterior segment bearing distally expanded lateral projections (sacral ribs) for extensive sutural contact with the ilium. By this definition, there are five sacral segments in AMNH 3040, OU 11, PU 16338, and YPM 5462.

In AMNH 3040, the last dorsal is coalesced with the first sacral, but the last two sacrals are not fused. This condition appears to be true also of YPM 5462, and OU 11. The sacral neural arches are incompletely preserved in PU 16338, but there is no fusion of any sacral centra. This may be an ontogenetic condition, although the neurocentral sutures are firmly united (if not fused) in all dorsals and caudals.

The sacral vertebrae of *Tenontosaurus* are a little less robust than the posterior dorsals. They resemble those of *Camptosaurus* in the deep and broad neural canal and the faint development of the "peg and notch"-like junction of adjacent sacral centra, as described in *Camptosaurus* by Marsh (1894) and Gilmore (1909). The present sacrals differ from those of *Camptosaurus* in lacking even a slight longitudinal groove along the inferior surfaces of the centra; *Tenontosaurus* sacrals show a broadly rounded ventral aspect.

The caudals of *Tenontosaurus* (Plate 18: I-N; Plate 19: A and B) constitute two thirds or more of the vertebral column, based on estimates from PU 16338 and AMNH 3040. The anterior caudal centra are short, deep and broad, with nearly flat lateral surfaces, strongly concave ventral surfaces and subcircular ends. The anterior neural spines are moderate in length, narrow, and curve back and upward—the anterior margin being concave rather than convex as in *Camptosaurus*. The neural spines of the anterior caudals also are relatively shorter and narrower than those of *Camptosaurus*. Moderate- to small-sized transverse processes occur on the first eight caudals, compared with the first 12 in *Camptosaurus*. The midcaudals are more elongate (length exceeds height and width), and the lateral surface is marked by an increasingly prominent longitudinal ridge, which produces a distinctly hexagonal outline to the ends of the centra. The neural spines are of moderate but decreasing height, straight, narrow, vertical and slightly expanded near the summits. The spine is reduced to a posteriorly placed, low, triangular blade near midtail, and gradually diminishes to nothing at the extremity.

The first chevron is situated between the first and second caudals. None of the present specimens permits a positive conclusion, but several indicate that the last 20 or so segments may have been free of chevrons. The type and the Princeton paratype show an absence of recognizable facets for chevrons, and in YPM 5466, a sequence of 33 medial and distal caudals has chevrons preserved with the first 10, but not the rest.

Ossified tendons are preserved in most of the specimens, closely associated with the neural spines and the chevrons (see Plate 19). The tendons along the dorsal series appear to have extended without interruption from the fourth or fifth dorsal back close to the tail extremity. The hypaxial tendons begin at about the fifth or sixth chevron and presumably extended to the caudal extremity. To the best of my knowledge, ossified hypaxial tendons have not been found in any other ornithopod except *Thescelosaurus neglectus* (Gilmore, 1915) and *Parksosaurus warreni* Parks, 1926. Sternberg (1940), in describing a second species of *Thescelosaurus* (*edmontonensis*), noted that no tendons were present along the underside of the tail in that specimen and suggested that this might be a youthful condition. Such may be the case in *Thescelosaurus edmontonensis*, but it apparently was not true in *Tenontosaurus*. Among the specimens in the Yale collections is a small juvenile (YPM 5478), less than one third the size of the largest specimen. Ossified tendons are well developed in this specimen, both above and below the caudals. (This is in a region of the tail that I would judge to be close to the 40th segment inasmuch as the centra have lost the hexagonal outline and measure 15 by 8 by 13 mm in length, height and width, respectively). There is no record of hypaxial tendons in *Camptosaurus*, although ossified epaxial tendons are preserved in several specimens.

Appendicular skeleton. The pectoral girdle of *Tenontosaurus* consists of scapulae, coracoids and sternals. The scapula and coracoid are virtually identical to those of *Camptosaurus*, except that the coracoid is more hook shaped anteriorly and the coracoid foramen is complete even in juveniles, whereas in *Camptosaurus* it is a notch open to the coracoid-scapula suture. Of particular interest is the presence of well-ossified sternal plates in every *Tenontosaurus* specimen in which the shoulder region is preserved. Although subsequent discoveries may alter this, at the present time sternal plates are unknown in *Camptosaurus*. They are not present in any of the several articulated skeletons, and the presumption is that they were not ossified. Sternal bones have been reported in *Iguanodon*, *Parksosaurus* (*Thescelosaurus warreni* Parks, 1926) and *Laosaurus* (Gilmore, 1925b), as well as in hadrosaurs. The *Tenontosaurus* sternals resemble those of *Parksosaurus*, with the exception that the posterior external margin curves forward more strongly. They are rather thin, but the anterior, medial and posterior margins are thickened for cartilaginous contact with the coracoid, the opposite sternal and sternal ribs.

The humerus appears to be less massive than in *Camptosaurus*, at least the shaft circumference to length ratio is less, but the deltopectoral crest and internal tuberosity are much more pronounced in *Tenontosaurus.* The radius and ulna also are somewhat less massive than in *Camptosaurus.*

The carpus apparently consists of three elements, presumably the radiale, ulnare and intermedium. Other carpals may have been present, but they are not preserved in place in any of the present specimens. Gilmore (1909) described eight carpals in *Camptosaurus*, the three mentioned above and five small distal carpals. A small lozenge-shaped element is present beneath the fourth metacarpal in BB 1, and this may represent a fourth or fifth carpal.

The manus (Plate 21: A) is distinct, being broader and flatter than that of *Camptosaurus.* The metacarpals particularly are broad and flat and somewhat longer than those of *Camptosaurus.* The phalangeal formula of *Tenontosaurus* is 2-3-3-2-2 (based on OU 11, BB 1, AMNH 3031 and YPM 5459), that of *Camptosaurus* is 2-3-3-3-2. The unguals of I, II and III are long and narrowly tapered compared to the broad, almost hooflike unguals of *Camptosaurus.* As in the Morrison species, the terminal phalanges of IV and V are small, nubbinlike elements.

The pelvic girdle (Plate 20: A, B and C) is perhaps the most distinctive postcranial structure and different from that of other ornithopods. The ilium is long, low and robust. It is distinctive in the very long and narrow anterior process that is bent sharply downward. Distally this process is parallel to the narrow, ventroanteriorly directed pubic peduncle. The ilium is also distinctive in the concave form of its upper margin. There is no evidence of an antitrochanter. The pubis differs from that of *Camptosaurus* in the short, straight and narrow form and horizontal projection of the prepubic blade and the straight and narrowly tapered form of the postpubic rod. The obturator foramen apparently is never closed off from the pubic-ischiac suture. The ischium differs from *Camptosaurus* in the straight, parallel-sided shaft that is not expanded distally. It resembles that of *Thescelosaurus*, except that the shaft is somewhat broader and the obturator process is more proximally placed in *Tenontosaurus.*

The limb, tarsus and pes are of normal iguanidontid construction. The limb elements, particularly the femur (Plate 20: D and E) and tibia, are appreciably less massive than those of *Camptosaurus.* The fourth trochanter is slightly less prominent and is more proximal in position in *Tenontosaurus.* The astragalus lacks an anterior ascending process, and neither the astragalus or calcaneum are ever fused to the tibia or fibula. In addition to the astragalus and calcaneum, the tarsus appears to consist of only two distal tarsals; at least that is all that is preserved in the numerous complete or nearly complete feet in present collections. Presumably these represent tarsals II-III and IV in that they articulate with metatarsals II, III and IV. A splintlike fifth metatarsal is preserved in two specimens (BB 1 and AMNH 3031). However, there is no scar or notch in metatarsal IV to indicate the presence of a fifth metatarsal, as there usually is when the latter occurs as a vestigial splint-line bone. The phalangeal formula is the normal 2-3-4-5-0, but the pes (Plate 21: B) of *Tenontosaurus* is distinct from *Camptosaurus* in the shorter length of the metatarsals relative to digit length, and in the unreduced form of metatarsal I, which has a fully developed proximal end and participates in the tarso-metarsal joint. In this, and in general proportions, the pes and metatarsus of *Tenontosaurus* are more like *Thescelosaurus neglectus* (USNM 7757) than anything else.

DISCUSSION: *Tenontosaurus* may be distinguished from *Camptosaurus* in the higher

TABLE 4. Principal measurements of *Tenontosaurus tilletti.*

Cranial Dimensions

	YPM 5456		YPM 5459		OU 11		PU 16338		AMNH 3040		BB 1	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Skull length (premax. to occipital condyle)	46.0			27±								
Skull width (maximum)	—			—								
height (quadrate artic. to parietal)	22.5		12±									
Maxillary tooth row length	20.0	18.5		—								
Orbit length	8.0	7.9	4.3									
height	6.2	6.8	6.1									
Lateral fenestra height	5.8	5.4		—								
length	—	5.9		—								
Mandible length	48.0±	45.0	26.0±									
Mandibular tooth row length	19.5	19.5		—	18.0	17.0						
Maxillary tooth positions	11	11		—	12	12						
Dentary tooth positions	12	13		—	13	12						
Vertebral Dimensions												
Length of odontoid and atlas intercentrum	3.6 + 3.0				3.5 + 4.0						2.4 + 2.5	
Axis, greatest length of centrum	5.5				4.7						3.6	
Axis, greatest height of centrum	—				3.5						3.4	
Axis, greatest width of centrum	5.5				4.6						3.2	
5th cervical centrum length	5.3				6.0						3.9	
height	5.3				4.9						3.4	
width	5.5				5.8						3.8	

10th cervical centrum	length	—		5.6			4.2
	height	—		5.0			4.1
	width	—		6.2			4.5
5th dorsal centrum	length			—	3.7	4.5	
	height			6.0	3.5	5.0	
	width			5.0±	3.3	4.7	
5th dorsal neural spine height				7.5	6.5	9.5	
10th dorsal centrum	length	?6.3		6.0	3.9	5.0	
	height	?6.3		6.5	4.2	5.5	
	width	?7.5		6.3	4.2	5.0	
10th dorsal neural spine height		?12.5	5.0±	12.5	7.4	9.5	
15th dorsal centrum	length		4.5	5.5	4.0	5.0	
	height			8.0	4.0	6.0	
	width			8.5	4.7	6.0	
15th dorsal neural spine height			9.0±	15.5	>8.0	11.5	
1st sacral centrum	length			6.0	4.0	5.5	
	height			6.5	—	6.0	
	width			9.0	5.8	6.6	
5th sacral centrum	length			6.0	3.8	5.0	4.0
	height			6.0	4.0	5.7	4.3
	width			7.0	4.5	7.0	5.0
1st caudal centrum	length	—			3.5	4.8	4.0
	height				4.5	6.2	5.0
	width				4.8	6.5	4.8
1st caudal neural spine height					11.5	14.0	>8.0
5th caudal centrum	length				4.0	5.0	4.5
	height				4.5	5.8	5.6
	width				4.1	5.2	4.8

Table 4. (continued)

<table>
<tr><th></th><th></th><th colspan="2">YPM 5456</th><th colspan="2">YPM 5459</th><th colspan="2">OU 11</th><th colspan="2">PU 16338</th><th colspan="2">AMNH 3040</th><th colspan="2">BB 1</th></tr>
<tr><th></th><th></th><th>Left</th><th>Right</th><th>Left</th><th>Right</th><th>Left</th><th>Right</th><th>Left</th><th>Right</th><th>Left</th><th>Right</th><th>Left</th><th>Right</th></tr>
<tr><td>5th caudal neural spine height</td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">13.5</td><td colspan="2">17.2</td><td colspan="2">14.5</td></tr>
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<tr><td></td><td>height</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">4.1</td><td colspan="2">5.0</td><td colspan="2">5.0</td></tr>
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<tr><td>20th caudal neural spine height</td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">8.0±</td><td colspan="2">9.0</td><td colspan="2"></td></tr>
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<tr><td>25th caudal neural spine height</td><td></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">—</td><td colspan="2">5.5</td><td colspan="2"></td></tr>
<tr><td>30th caudal centrum</td><td>length</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">?5.5</td><td colspan="2">4.6</td><td colspan="2">6.5</td><td colspan="2"></td></tr>
<tr><td></td><td>height</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">?3.2</td><td colspan="2">2.5</td><td colspan="2">3.4</td><td colspan="2"></td></tr>
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<tr><td></td><td>width</td><td colspan="2"></td><td colspan="2"></td><td colspan="2">?3.1</td><td colspan="2">2.5</td><td colspan="2">3.5</td><td colspan="2"></td></tr>
</table>

40th caudal centrum	length	3.8	—
	height	1.7	—
	width	2.1	—
45th caudal centrum	length	3.3	4.7
	height	1.3	2.1
	width	1.8	2.7
50th caudal centrum	length	3.2	—
	height	1.2	—
	width	1.6	—
55th caudal centrum	length	2.5	—
	height	0.8	—
	width	1.2	—
58th caudal centrum	length	2.5	—
	height	0.7	—
	width	1.1	—

Pectoral Girdle and Fore Limb Dimensions

Scapula length		52.5	54.5	33	34.5	45	46			—
maximum width		18.0	18.2	6.4	—	17.5	17			8.0
Coracoid length		20.0	19.5			22	22	12.5	12.5	12.5
height		14.5	14.0			15	17	10.5	10.2	8.5
Sternal length		18.0	—			23.5	22	13.0	13.1	—
Humerus	length	43.5	46.5			44.2	44			27.2
	proximal width	—	13.5			14	15.5			9.2
	distal width	12.0	11.5	9.5	8.5	11.3	13			7.5
Deltopectoral crest length		23.5	26.5			25	25			13.5
Humerus shaft circumference		—	—	—		15.8	16			10.0
Ulna	length	34	30±	22.5		34	34			21.5
	proximal width	—	9.0	8.5		11	10			7.0
	distal width	—	—	—		6.5	6.5			4.1
Radius	length	32	26±	21.0		33	33			20.5
	proximal width	5.7	7.5	4.0		7.0	7.3			4.5
	distal width	6.3	—	—		8.0	7.0			4.5

TABLE 4. (continued)

	YPM 5456		YPM 5459		OU 11		PU 16338		AMNH 3040		BB 1	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Length Metacarpal I			3.5		6.7	6.2					—	
Metacarpal II			5.6		9.2	9.3					6.2	
Metacarpal III			7.2		9.4	—					6.6	
Metacarpal IV			7.4		7.1	7.2					4.8	
Metacarpal V			4.2		5.3	—					3.4	
digit I					8.0	8.0					—	
digit II					—	9.0					6.0±	
digit III					9.8	—					5.6	
digit IV					4.5	—					2.0	
digit V					3.0±	3.0					—	
Pelvic Girdle and Hind Limb Dimensions												
Ilium length				—	—	51.0	28.0	28.5	42.0	42.0		
height at acetabulum				9.2±	—	11.0	7.0	6.5	8.7	9.0	7.2	
Ischium length					56.5	55.5	34.0	35.5	—	46.0	29.5	
distal width					6.5	7.0	5.0	5.0	—	7.0	—	
Prepubic blade length					17.0	18.0	13.2	14.3	—	23.2		
height					4.5	4.7	2.6	2.7	—	5.2		
Postpubic rod length behind obturator foramen					—	—	>16.5	—	—	>27.0		
Femur length			41.5		57.0	58.0	35.5	35.5	—	48.0	—	
proximal width			—		—	12.0	9.5	9.5	—	13.5	—	
distal width			12.5		16.5	15.0	10.7	11.0	—	>14.0	10.5	
Distance from femur head to 4th trochanter			—		>29.0	30.7	18.2	18.6	—	26.5	—	
Femur minimum circumference			—		23.0	22.5	14.0	14.0	—	20.2	14.5±	

Tibia	length	50.0		53.5	35.0	33.5	35.0
	proximal width	—		—	10.5	10.0	10.0
	distal width	10.5		—	10.3	11.0	10.8
Fibula	length	49.2		51±	31.7	32.8	32.5
	proximal width	5.0±		—	6.8	6.2	7.0
	distal width	—		—	2.4	3.8	4.0±
Astragalus length		—			3.3	3.2	2.5
width					5.9	6.1	5.5
Calcaneum width					4.4	4.2	—
Metatarsal I length			14.0		8.6	8.5	9.0
Metatarsal II			18.5		12.2	12.5	13.0
Metatarsal III			21.5		13.7	14.0	14.5
Metatarsal IV			18.0		11.3	11.5	11.8
Digit I length			>14.0		9.5	9.5±	10.5
Digit II			18.0		12.5	13.5	14.0
Digit III		19.5	21.5		14.5	14.8±	17.0
Digit IV		13.0	19.5		15.0	15.0	15.0

All measurements in centimeters.
? indicates segment number is doubtful.
± indicates measurement is only approximate.

presacral count (28), much longer tail, ossified hypaxial caudal tendons, distinctive form of ilium, ischium and pubis, lesser robustness of all limb bones, the presence of sternals, the manus phalangeal formula of 2-3-3-2-2, the form of the metatarsus and tarsus, and a whole suite of cranial characters, including the presence of a subsidiary lateral temporal fenestra, a fissurelike antorbital fenestra, narrow and straight quadrate, compressed basicranium, tooth morphology, "double" coronoid process and the very deep, narrow form of the skull. Some of the same features also distinguish *Tenontosaurus* from *Thescelosaurus*: the higher caudal count, the form of the pelvic elements, the presence of sternals, and the manus formula. In addition, the morphology of the caudal vertebrae, the higher position of the fourth trochanter and the shapes of the scapula and humerus are distinct from *Thescelosaurus neglectus*, and dental and mandibular morphology, and sacral count distinguish it from *Thescelosaurus edmontonensis*. *Parksosaurus* differs from the present species in dental morphology, the slender jugal and deep, lateral temporal fenestra, orientation of the antorbital fenestra, six sacrals, shorter tail, the shapes of pelvic elements, the lower position of the fourth trochanter and the reduced first metatarsal. *Laosaurus* differs in the shape of the humerus, the higher position of the fourth trochanter and the relatively longer and more slender metatarsals and phalanges of the pes. *Laosaurus* also appears to have a robust supraorbital bar and a supraorbital fenestra, rather than the slender tapered supraorbital of *Tenontosaurus*. *Dryosaurus* is separate from *Tenontosaurus* in the shape and position of the antorbital fenestra, the shape of the lateral temporal fenestra, the presence of a supraorbital fenestra and the relative proportions of the skull. It differs also in having six sacrals, a very long, low ilium with a convex upper margin, and a slender and elongated metatarsus. *Iguanodon* resembles the present species in general form of the skull, but differs in having a lower snout, a shallow jugal arch, a smaller orbit but larger lateral fenestra, lack of a subsidiary lateral fenestra, the closer spacing of teeth, the vertebral count, the form and formula of the manus and the shapes of ilium, ischium and pubis.

Laosaurus and *Camptosaurus* are clearly distinct. *Dryosaurus* may be synonymous with *Laosaurus*, but further preparation and study of the types of *Laosaurus gracilis* (YPM 1875) and *Dryosaurus altus* (YPM 1876), and the two Carnegie Museum skulls (CM 11340 and 3392) referred to these last two genera is necessary before the matter can be resolved. Until such time as that is accomplished, or new and more complete material is discovered, it is impossible to draw any firm conclusions about the affinities of *Tenontosaurus* with either *Laosaurus* or *Dryosaurus*.

The skull of *Camptosaurus* is not well known despite the restorations given by Gilmore (1909). Consequently it is difficult to make adequate comparisons with the present material. The differences in postcranial osteology between *Camptosaurus* and *Tenontosaurus* do not preclude an ancestral-descendant relationship. The reduced manus, the complete first metatarsal, the increased vertebral count, the pelvic and pectoral girdle features could all have been derived from the *Camptosaurus* condition. Thus, the cranial evidence is critical, and the inadequate nature of the *Camptosaurus* skull material makes final judgment difficult.

Examination of all known cranial material has led me to conclude that Gilmore's reconstruction of the skull of *Camptosaurus* is correct in most details. Those points that I have reservations about (the long length of the lower premaxillary lobe, the very short upper premaxillary process, the position and shape of the quadratojugal, and the form of the paroccipital process) do not alter the most significant aspects of Gilmore's reconstruction, which is of a long and very low and broad skull. Virtually all adequately known ornithopods are characterized by deep and relatively narrow skulls with long, nearly straight and vertical quadrates, deep pterygoids and long, ventrally directed basipterygoid processes. These conditions are true of the few known Triassic forms (*Heterodontosaurus, Fabrosaurus*) and apparently were true for other Jurassic ornithopods (*Laosaurus, Dryosaurus*? and *Dysalotasaurus*) and many Cretaceous species (*Hypsilophodon, Iguanodon* and nearly all hadrosaurs). It may have been true of *Thescelosaurus*, but it appears not to have been characteristic of *Parksosaurus. Camptosaurus* would thus seem to be an exception with its long and low, broad skull, short and curved quadrates, and short and ventrolaterally directed basipterygoid processes. These suggest that *Camptosaurus* may have been an aberrant line and not ancestral to *Tenontosaurus* or any of the other well-known Cretaceous ornithopods.

Gilmore (1909) proposed a new species of *Camptosaurus* (*C. depressus*) for a very fragmentary specimen (USNM 4753), from what has been called "Lakota sandstone", of possible Early Cretaceous age, at Calico Canyon near Buffalo Gap, South Dakota. The precise stratigraphic level and age have not been determined. The possible Early Cretaceous age of this specimen invites comparison with *Tenontosaurus*.

The specimen, which consists of portions of both ilia, one pubis(?), an incomplete sacrum, a sacro-dorsal, 12 caudals and a few rib fragments, is at best a doubtful type specimen. Comparison with other *Camptosaurus* materials suggests that it may represent a distinct species, but it is also possible that the diagnostic features noted by Gilmore are due to individual variation.

Whether or not *C. depressus* is a valid species, there can be no doubt about its distinction from *Tenontosaurus*. The ilia of *C. depressus* lack the concave upper margin, and the long anterior process of the ilium is straight and projects forward and only slightly downward, whereas that of *Tenontosaurus* turns very sharply downward. Also, this anterior process is very robust and triangular in section in *C. depressus*. In *Tenontosaurus* it is very thin transversely and bladelike. The caudal vertebrae are incomplete, but at least one anterior caudal bears a rodlike neural spine that is inclined backward at approximately 45°, instead of being bladelike and nearly vertical. The distal caudals also appear to have had short neural arches instead of the nearly full-length arches characteristic of *Tenontosaurus*.

Inadequate as the type of *C. depressus* is, I see no evidence to equate it with *Tenontosaurus*, but there appears to be good evidence for considering the two as distinct.

Suborder ANKYLOSAURIA

Family ACANTHOPHOLIDAE Romer, 1927

Sauropelta, new genus

ETYMOLOGY: *Sauros* (Greek; masculine), lizard, and *pelta* (Greek; feminine), small shield, in reference to dermal armor.

TYPE SPECIES: *Sauropelta edwardsi*, new species.

DIAGNOSIS: Same as that of the type and only species.

Sauropelta edwardsi, new species

Plates 22-27

ETYMOLOGY: *Sauropelta edwardsi;* named for Nell and Tom Edwards of Bridger, Montana, in appreciation of the hospitality and assistance they gave to Yale field crews.

TYPE SPECIMEN: AMNH 3032, a partial skeleton, lacking the skull.

TYPE LOCALITY: AMNH 32-3, NE ¼ Sec. 20, T.5 S., R.28 E., Big Horn County, Montana. Unit V, VI or VII (precise stratigraphic level unknown) of the Cloverly Formation.

REFERRED SPECIMENS: Partial skeletons (AMNH 3016, 3033, 3035, 3036, 5833, 5853); isolated elements[5] (YPM 4896, 5069, 5072, 5074, 5086, 5094, 5095, 5098, 5101, 5102, 5105, 5106, 5108, 5109, 5111-5115, 5118-5122, 5124, 5125, 5127, 5130, 5131, 5133, 5134, 5136, 5137, 5139-5146, 5148-5150, 5154-5159, 5161, 5163-5169, 5173, 5175-5179, 5181-5189, 5191, 5192, 5194, 5196, 5198, 5200, 5295-5298, 5300-5305, 5307, 5309-5315, 5317, 5320-5327, 5333-5341, 5350-5352, 5367, 5368, 5389, 5391, 5393, 5402, 5405, 5408, 5409, 5442, 5448, 5486-5503, 5505-5513, 5516, 5517, 5520-5522, 5525-5529, 5531, 5532).

ADDITIONAL REFERRED SPECIMENS: AMNH 3064; YPM 4892, 4897, 4905, 5076-5078, 5085, 5125, 5136, 5140, 5150, 5190, 5193, 5306, 5308, 5316, 5318, 5319, 5328, 5330-5332, 5390, 5394, 5395, 5406, 5485, 5504, 5515, 5536.

LOCALITIES: AMNH 03-28, 04-9, 31-9, 32-4, 32-6, 32-7, 38-2; YPM 62-11, 63-16, 63-17, 63-18, 63-19, 63-20, 63-22, 64-20, 64-23, 64-24, 64-29, 64-31, 64-47, 64-67.

DISTRIBUTION: Units V, VI and VII, Cloverly Formation, southern Montana and northern Wyoming.

DIAGNOSIS: Medium-sized acantholid ankylosaur with extensive dorsal and flank armor consisting of a mosaic of large flat and keeled dermal plates interspersed with small plates and irregular ossicles. Flank armor consists of large hollow-based plates projecting lateroposteriorly as long triangular spines. Skull inadequately known, but apparently relatively long and deep, and perhaps narrower than in other ankylosaurs. Lateral temporal fenestra present, but upper fenestra closed by dermal ossifications. Mandible long, with low coronoid process, and co-ossified with a superficial dermal plate. The latter does not extend onto inferior medial surface. Mandibular tooth row long, extending almost to symphysis. Mandible tooth count 25 to 27. Teeth of ankylosaurid type with laterally compressed crowns triangular in lateral aspect and denticulate along anterior and posterior edges. External and internal surfaces usually not striated or ridged, but crown base irregularly and variably inflated to produce a bulbous labial cingulum and a narrow lingual cingulum. Either or both cingula may be absent. Cervical vertebrae short, massive and wide. Width of centrum exceeds length and height, and centra faces oval and amphiplatyan. Neural canal very large. Neural

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[5] Disarticulated and scattered scutes, vertebrae, ribs, limb bones and skull and jaw fragments of at least five individuals were collected in the six closely spaced Yale sites (YPM 63-16, 63-17, 63-18, 63-19, 63-20 and 63-22). There being no way to establish true associations of most elements, the majority have been catalogued as individual entries.

arch low, diapophyses short, massive and projecting laterally, neural spines low, robust and triangular. Inferior surface of centra with a broad, shallow longitudinal groove bordered laterally by thin, ventrolaterally projecting laminae. Dorsal centra long, constricted laterally and ventrally at midlength, terminal faces circular and amphiplatyan. Neural arches high, with high oval neural canal. Diapophyses stout, short, and extend up and outward at 50 to 60° to horizontal. Both diapophyses and short bladelike neural spines expanded distally, the latter both transversely and longitudinally. Postzygapophyses overhang well behind the centrum posterior surface. Ribs not co-ossified to vertebrae. Proximal caudal centra short, but very deep and wide, nearly circular in end view and amphiplatyan. Transverse processes project out and downward proximally, but become horizontal posteriorly. Neural spines stout, short and greatly expanded distally. Distal caudals elongate, hexagonal in end view and with a narrow, deep midline groove ventrally (haemal canal). Large, projectant chevron facets at posterior inferior margins of centra, but little or no facet anteriorly. Chevrons infrequently fused to centra. Fore limb short and massive with very heavy humerus and short, stout radius and ulna. Manus phalangeal formula unknown. Scapula-coracoid fused, very massive, short and downcurved both anteriorly and posteriorly. Sacrum consists of seven or eight segments. Ilia greatly expanded into near horizontal plates overhanging far lateral to acetabulae and with long narrow anterior blades. Ischium a simple rod, strongly downcurved distally, but without any distal expansion. Pubis greatly reduced to small hook-shaped element. Hind limb long, with stout and long femur and moderately elongated tibia and fibula. Tarsus unknown, but pes phalangeal formula 2-3-4-5?-0. All digits terminate in flat, hooflike unguals.

DESCRIPTION: Ankylosaur remains are rather common in fossil vertebrate collections from the Cloverly Formation and appear to be second only to *Tenontosaurus* in abundance. No complete skeletons are known, however; in fact, other than numerous isolated elements, only four partial skeletons exist in addition to the type specimen. It is quite possible that more than one species[6] is represented among the items here referred to *Sauropelta*, but no concrete evidence to that effect is available at present. Accordingly the following description and the preceding diagnosis are based on the type specimen (AMNH 3032) where possible, but other specimens in the American Museum and Peabody Museum collections have been used for characterization of those elements not preserved in the type. In particular, I call attention to the Yale Crooked Creek quarries of northern Wyoming (YPM localities 63-16, 63-17, 63-18, 63-19 and 63-20) that produced large numbers of ankylosaur scutes and postcranial bones. At these sites, ankylosaur remains were the most abundant materials by far, but nearly all were disarticulated and occurred as isolated elements. At least five individuals are involved here and nearly every skeletal part is represented. Comparable elements are indistinguishable from those of the type, and it is concluded that the type specimen and all Crooked Creek ankylosaur remains are of a single species. Thus the Crooked Creek materials have been used extensively in this description.

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[6] The most suggestive evidence of a second species lies in the "unique" armor preserved in AMNH 3036 which seemingly lacks any hollow-based spikes or strongly keeled plates, both of which are abundantly represented in the other partial skeletons known and in the isolated ankylosaur remains. (See Plate 27: G to L for the keeled and hollow-based scutes and compare with Plate 75, Colbert, 1961 for the dermal armor of AMNH 3036.)

Skull. The skull is missing in the type specimen, but a partial skull is present in AMNH 3035 and several skull fragments were recovered from Yale locality YPM 63-19 (YPM 5528, 5529, 5499). Although poorly preserved and lacking much of the preorbital region, the skull of AMNH 3035 appears to have been significantly higher than most nodosaur skulls. The skull roof, which is veneered with thick dermal ossifications, lies approximately 12 cm above the ventral margin of the foramen magnum, equal to half the skull width at the orbits (25 cm). This compares with 8 and 30 cm in *Edmontonia rugosidens* (USNM 11868) and 8 and 28 cm in *E. rugosidens* (ROM 1215). A low or depressed skull also appears to be characteristic of *Panoplosaurus miris* (NMC 2759) and *Silvisaurus condrayi* (UKM 10296). The skull roof of *Sauropelta* appears to have been flat and completely covered with dermal bone concealing all dorsal and lateral bones and sutures. Greatest skull width is just behind the orbits and equals about 35 cm. The orbits are small and appear to have been oval with a maximum diameter (length) of about 6 cm. Although portions of the circumorbital area and maxilla are present in the type, no sutures are recognizable and little can be said about precise relationships. The right and left circumorbital regions are also known from fragments collected at Yale site YPM 63-19. In both, the skull bones are covered by small- to moderate-sized, knobby or flat dermal ossifications. Several prominent sulci are preserved, particularly one extending from the rear margin of the orbit across the supraorbital rim and medially across the lateral part of the skull roof. Thus the dermal scutes overlying the orbital region might be described as preorbital and postorbital scutes. This same pattern occurs in *Edmontonia rugosidens* (USNM 11868 and ROM 1215) and, contrary to Gilmore's statement (1930, p. 3), there does appear to be some uniformity of sulci and scute patterns.

The lateral temporal fenestra is not recognizable in this specimen, but an isolated left quadrate (YPM 5529), with a complete anterior margin, shows that at least a small lateral fenestra was present. The quadrate flares out slightly ventrally and appears to have sloped forward and slightly outward as in most ankylosaurs, at approximately 60° to the vertical. As a consequence of this forward inclination of the quadrate, the broad distal extremities of the quadrates are situated lateral to the anterior end of the basicranium, and the stout pterygoid flanges extend directly medial. Moderate-sized posttemporal fenestra are present on either side of the braincase between the exoccipital and the pterygoid flange of the quadrate. The occipital surface is broad and low and, although no sutures are discernible, appears to be constructed entirely of the exoccipitals and supraoccipital. The small subspherical condyle (4.5 cm) is formed exclusively of the basioccipital. This structure points down and back at a sharp angle to the tooth row, but I agree with Lambe (1919) and Russell (1940) that the ankylosaur skull in life was probably held at an inclined angle of perhaps as much as 60° to the horizontal. Thus in the normal position the quadrates are nearly vertical and the occipital condyle projects back horizontally. This position appears to be verified by the attitude of the floor of the endocranial cavity and what appears to be part of the semicircular canal cavity preserved in an isolated fragmentary braincase (YPM 5529).

The braincase is very massive and short. The basioccipital-basisphenoid junction is greatly inflated ventrally and marked by two irregular lateral projections (basisphenoid tubercles) and a broad midline swelling. A large foramen, presumably for the internal carotid artery, pierces each side of the basiphenoid well below the endocranial cavity and passes into the pituitary fossa. Immediately anterior to this, the basicranium narrows abruptly and passes forward as a thin sagittal blade (parasphenoid) above the fused pterygoids. The inflated basisphenoid butts closely against the posterior surfaces of the broad pterygoids. In normal articulation the basipterygoid processes are concealed, but the isolated basicranium (YPM 5529) shows a very short knob-like projection on the left side that appears to be a vestige of that process. Nevertheless, there appears to have been complete immobility between endocranium and palatoquadrate.

Mandible. Portions of the right mandible are preserved in AMNH 3035, but again no teeth are visible. Its length is approximately 35 cm from the center of the glenoid to the symphyseal region and it bears a low triangular coronoid that rises approximately 13 cm above the ventral margin of the mandible. The tooth row is long and curved, but no count of alveoli can be made. The right mandible is imperfectly preserved in the type. It compares exactly with the above mandible and a Yale specimen (described below) and includes a long tooth row (23 cm) with 27 alveoli that extends very close to the symphysis.

Several isolated mandibles were collected at various Yale sites, among them one excellent jaw (YPM 5502) illustrated in Plate 22: A, B and C that provides the following details. It is of moderately massive construction but tapers to a narrow symphysis. The length is 37 cm and the height at the coronoid process is 11.3 cm. The most distinctive feature is the long, curved tooth row (20 cm minimum length, 22 cm along the curve) with 25 alveoli. A second jaw (YPM 5391) also has 25 alveoli. This compares with 18 alveoli and a straight length of 14.5 cm in a mandible 35.2 cm long for *Edmontonia rugosidens* (USNM 11868). The long tooth row reaches to within 3.5 cm of the symphysis and extends farther forward than in any nodosaur except *Silvisaurus*. Eaton (1960) reported "about 27" mandibular alveoli extending to within 25 mm of the symphysis and measuring (in a straight line) 170 mm back from the symphysis. *Silvisaurus* is the only nodosaur(?) in which premaxillary teeth are known (and for this reason it should perhaps be referred to the Acanthopholidae), but the long mandibular tooth row in the present material certainly indicates their probable existence in *Sauropelta*.

The tooth row curves markedly over its length, concave externally. It also curves in the vertical plane with anterior and posterior teeth situated at a much lower level than those near midlength.

The external mandibular surface is marked by a long and broad rugose or sculptured region—a dermal ossification that has fused to the mandible. This dermal plate does not reach either to the symphysis or over the short retroarticular process. The "exposed" posterior portion of the mandible behind the dermal plate marks the positions of the pterygoideus muscles that probably inserted on the external surface behind this scute and wrapped around beneath the mandible and passed forward to the greatly expanded pterygoids. The upper limit of the dermal ossification is well below (approximately 3 cm) the tooth row and parallels it to the base of the coronoid process. Eight large foramina pierce the dentary in this region between the tooth row and the dermal scute and two more occur close to the symphysis. Unlike most nodosaurs, this superficial dermal ossification has a sharply defined ventral margin along the inferior margin of the mandible and does not extend up onto the inner surface of the jaw.

The internal aspect of the mandible is smooth and gently concave. A row of prominent round foramina lies just below the alveolar margin. They correspond one for one with the alveoli and presumably functioned as passages for germ teeth from the dental lamina as suggested by Edmund (1957). Four other large foramina appear to penetrate the inner wall of the mandible to the Meckelian canal, one each at the anterior and posterior ends of the splenial and one at the top and one at the center of the splenial. This last bone overlaps the dentary as a thin sheet of bone, is triangular and extends over the middle third of the jaw. Posteriorly it unites by a firm digitate suture with the angular. Dorsally it contacts the coronoid and ventrally, over part of its length, it joins the external dermal ossification. Near the rear extremity of the tooth row the splenial height is slightly less than the dentary height. In *Edmontonia* it appears to be comparable, although Russell (1940) shows it as a thin sliver of bone along the lower internal surface.

The coronoid is a narrow L-shaped bone, the anterior process of which loosely overlaps the last six dental foramina, immediately lingual to the tooth row. The posterior or dorsal process laps over the anterior edge of the coronoid process (dentary?) and fuses solidly with that structure.

The angular is solidly united with the other postdentary bones and all sutures are obliterated. Presumably, the mandible medial, ventral and posterior to the Meckelian canal, is composed of the angular, surangular, articular and prearticular, but none are recognizable. The surangular presumably forms the posterior part of the coronoid process and the external surfaces of the region behind. A small foramen (the surangular foramen?) penetrates this area at the posterior edge of the dermal ossification and opens into the rear of the mandibular fossa 2 cm anteriorly. The glenoid region is separated from the floor of the mandibular fossa by a prominent transverse ridge. The articular area itself is broad transversely and consists of two large, shallow concavities in an oblique trend, the larger one situated lateral and slightly behind the other. These extend almost to the end of the short, but robust retroarticular process.

The symphysis is moderately wide (from front to back) but surprisingly shallow. In fact, the symphyseal region is the shallowest part of the mandible except for the retroarticular process. The symphyseal surface is marked by broad, shallow depressions, and the upper superficial region just lateral and anterior to the symphysis bears numerous deep pits and bosses or tubercles. These features suggest a cartilaginous or ligamentous union of the mandibles that may have been somewhat mobile. There is no clearcut scar for a predentary that is identifiable as such.

Teeth. Ten functional and replacement teeth are preserved in mandible YPM 5502. An additional seven replacement teeth are visible in the second mandible, YPM 5391. Two teeth are preserved in place in a maxilla fragment (YPM 5368) and 20 isolated teeth were recovered from several sites (see Plate 22: D, E and F). There seem to be no consistent differences between maxillary and dentary teeth. All are laterally compressed, triangular blades with denticulate anterior and posterior margins. The number of denticles varies from three to five on one edge and five to seven on the other, exclusive of the apical denticle. The higher denticle count appears to be always on the anterior edge, but this cannot be confirmed with the present limited sample. There is moderate variation in crown height, with some being relatively low and broadly triangular, others high and more narrowly tapered, as shown in Plate 22: D, E and F.

The basal part of the crown is inflated to variable degrees and usually is developed into an irregular cingulum. This structure is most prominent on the external side of lower teeth but may be present on either or both sides. However, a cingulum apparently is not universally present, as several teeth in the Yale collections (YPM 5525, 5502) show (Pl. 22: E). Below the crown, the cylindrical root is constricted and then expands slightly before tapering to its extremity. All teeth appear to have had open roots.

The only apparent difference between the present material and teeth of nodosaurs is the absence of even faint vertical rugae across the inner and outer crown faces. Such rugae are prominent features in *Ankylosaurus magniventris* (AMNH 5895), *Edmontonia longiceps* (NMC 8531), *Edmontonia rugosidens* (USNM 11868), *Panoplosaurus miris* (NMC 2759) and all species of *Palaeoscincus.* Only *Silvisaurus condrayi* (UKM 10296) similarly lacks these rugae, further evidence for allying these species.

Vertebral column. The vertebral count is not known for *Sauropelta*, but representative vertebrae are available for all parts of the column. No cervical vertebrae are preserved in the type specimen, but six cervicals are present, either completely or in part, in AMNH 3035. Among those represented are the atlas and axis. In contrast to all nodosaurs, only the odontoid is fused to the axis. The remainder of the atlas is missing, but it is quite evident that the altas intercentrum and arch were not coossified with the axis (see Plate 22: G). This condition is found in primitive acanthopholid ankylosaurs (i.e. *Struthiosaurus transsylvanicus*, Nopcsa, 1929), but not, as far as I know, in any nodosaur.

The odontoid is moderately long, tapers anteriorly, both in lateral and dorsal views. The upper surface is concave from side to side, but the ventral surface is narrowly convex, almost "keeled", so that in anterior aspect the odontoid is almost triangular.

The axis centrum is long and low, oval in end view and moderately concave in its posterior surface. The underside of the centrum is broad and nearly flat, with a thin, sheetlike lamina of bone projecting back from the anterior edge. This may represent a greatly flattened and backward-directed hypopophysis. The lateral centra surfaces are marked by a large but short parapophysis at midheight and close to the anterior margin. The neural pedicels are high, enclosing a very large, vertically ovate neural canal. Short, stubby transverse processes project directly laterally from the pedicels at midheight of the neural canal. The postzygapophyses are large, projecting backward beyond the posterior face of the centrum. In contrast to nodosaurids, particularly *Edmontonia rugosidens* (USNM 11868), the neural spine is a very low triangular knob overlying the postzygapophyses.

The other cervicals, presumably the third through fifth (Plate 22: I and J), are shorter in centrum length but have the same low oval outline in axial view. These centra are amphiplatyan and slightly angled, reflecting a slight arch to the neck. The ventral surface is broad with a shallow sagittal groove and low but distinct lateral ridges. The neural arch is high and broad, with short, horizontal diapophyses and short, robust and sub-bladelike neural spines.

Thirteen dorsals are present in the type specimen, but few are complete, and the number of missing segments is not known. Unfortunately, all information about the relationships of these segments is lost, so none can be identified as to position with absolute certainty. Dimensions are similar enough and preservation capricious enough to frustrate establishment of sequences based on length, height or width of the centra (see Plate 22: K; and Plate 23: A).

All dorsals are amphiplatyan, but many show a faint central convexity 2 to 3 cm in diameter on both anterior and posterior centra surfaces. Both ends are nearly circular with height slightly greater than width. The sides and under surfaces are smooth and strongly concave longitudinally. No pleurocoels are present. The neural arch pedicels are very high and narrow, enclosing a high, elliptical canal. The parapophyses are high on the pedicels, well above the level of the neural canal, and project only slightly outward. Pre- and postzygapophyses are very close to the midline and are joined. The postzygapophyses project well behind the centrum and directly above the neural canal. Whereas the zygapophyseal facets of the cervicals are inclined at a low angle of 20 to 30° to the horizontal, those of the dorsals are steeply inclined at 60° or more. The transverse processes are long and project up and out (not backward) at a very steep angle of close to 60°. None are complete but these are quite stout and apparently were expanded distally. They appear to have terminated at the level of the neural spine summit. The neural spine is a stout blade with an upright and very backward orientation. It is rectangular, thin transversely, and the summit is swollen both transversely and longitudinally.

A complete sacral series is not known for *Sauropelta*. The type includes seven fused segments of which the last four probably are true sacrals and the first three (and possible additional segments) are fused posterior dorsals. The posterior elements are moderately broad ventrally, the remainder are narrow and strongly rounded transversely. Sacral ribs are evident in only four of the segments. YPM 5102 is the major part of a sacrum, including the neural arch pedicels and massive sacral ribs. Five segments are present, all solidly fused. The most anterior segment may be a dorsosacral, but the remaining four are true sacrals. The transverse widths of the centra increase markedly from front to back, as does the diameter of the neural canal. The maximum diameter of the latter occurs at the last sacral.

Silvisaurus is characterized by six sacrals and six additional segments fused into a presacral rod. Gilmore (1930) described three sacrals, four presacrals and two sacrocaudals coalesced into a "synsacrum". This number corresponds with *Nodosaurus textilis* as described by Lull (1921) but is three more than reported in *Panoplosaurus miris* by Sternberg (1921) who recognized four sacrals, one dorsosacral and one sacrocaudal. Obviously, there is considerable variation in sacral count (or interpretation) within the Nodosauridae, and the incomplete remains of *Sauropelta* presently prevent establishment of sacral count in this genus.

Thirty-nine caudal vertebrae (Plate 23: B-E) are preserved in the type specimen, but the series is incomplete with an unknown number of segments missing from the extremity and within the series. Unfortunately, field data again are not available and the original sequence of these vertebrae is unknown. Seventeen bear prominent to very long transverse processes; the remainder lack this structure and are clearly distal segments. All caudal centra are amphiplatyan with the anterior face slightly concave. Proximal caudal centra are short but high and broad, the breadth being slightly greater than the height. Centra faces are nearly circular. Long, stout, rodlike transverse processes project out and downward from the most proximal caudals. These become nearly horizontal in succeeding segments. The neural arch is low and robust and bears a short, massive neural spine that is inclined up and backward (the anterior margin being concave) and terminates in a prominent knob. Both pre- and postzygapophyses overhang the centra faces and the anticular facets are inclined (45°) and separated at the midline.

Distal caudals are much longer than they are wide or high, and centra are distinctly hexagonal in end view. The lateral surfaces are often marked by several slight, longitudinal ridges, and the ventral surfaces consist of a deep, narrow midline groove bordered by prominent lateral ridges extending between anterior and posterior chevron facets. The neural arch is low and extends over one half to two thirds of centrum length. Neural spines are thin and diminish from short bladelike structures to low, caudally projecting triangles. In anterior caudals, the articular facets for the chevrons occur as prominent ventral projections only at the rear margins of the centra. In posterior caudals, chevron facets occur at both anterior and posterior margins but the latter are most prominent.

The chevrons are short, massive blades that occasionally fuse to the centrum anterior to it.

Ossified tendons are preserved in contact with several dorsals and caudals in the Yale collections, but in each instance they are fragmentary and nothing can be said about their frequency, arrangement or distribution along the vertebral column. The best evidence of tendons is preserved on both sides of the neural arches of the sacrum YPM 5102, but again the evidence is fragmentary. These are rodlike ossifications, probably of the epaxial musculature, and presumably they extended along the vertebral column from the anterior or middorsals to at least midtail.

Ribs. The dorsal ribs are well represented in the type specimen, as well as in the Yale collections from localities YPM 63-18 and 63-19. None of these are fused to the dorsal vertebrae, contrary to the usual condition in nodosaurs. All appear to have been massive and T- or L-shaped in cross-section, and all are double-headed. Cervical ribs are short and Y-shaped.

Shoulder girdle. The shoulder girdle elements (Plate 24: A and B) are damaged and incomplete in the type specimen, but the right side is preserved in AMNH 3035 and several scapulo-coracoids are represented in the Yale collections. The shoulder girdle appears to have consisted only of a very massive, fused scapulo-coracoid, as no evidence of either sternals or clavicles (see Russell, 1940) has been recognized. The scapulo-coracoid consists of a short, strongly curved, thick scapula and a very large, crescentic coracoid. Both elements are very massive but particularly so at the glenoid. For example, in AMNH 3035 the transverse thickness of the scapula at the glenoid is approximately 12 cm and the least width of the scapular blade is 10 cm (maximum width is 16 cm at the extremity). A robust, knoblike acromion process projects forward and laterally from the upper proximal external surface of the scapula, directly above the rear margin of the glenoid. The scapular blade thins slightly distally and curves strongly downward. Internally its surface is strongly concave.

The coracoid is firmly fused to the scapula with all signs of the suture obliterated. The margins are moderately thick, but maximum thickness of 11 cm is attained adjacent to the glenoid. The coracoid foramen is large and oval and extends inward and backward from the external surface. In general form, the scapulo-coracoid is nearly identical to those of most nodosaurs and particularly that illustrated by Sternberg (1921) of *Panoplosaurus.*

Fore limb. As in all nodosaurs, the humerus of *Sauropelta* is a short and very massive bone (Plate 24: C and D). Both humeri are present in the type; the left is also present in AMNH 3035, and numerous others are represented in the Yale and American Museum collections. In addition to its massive form, the most distinctive feature of the humerus is its short length relative to that of the femur. In the type specimen, the humerus is approximately three quarters the length of the femur (0.72 to 0.77). The shaft is nearly straight and is marked by a very long, stout deltopectoral crest along its proximal half that apparently extends forward nearly perpendicular to the long axis of the distal extremity. The head is robust and subspherical, projecting back well behind the shaft in a direction perpendicular to the long axis of the distal extremity. The distal condyles are large, the external condyle being the larger. The two condyles are separated by a broad, shallow groove distally and anteriorly and there is a moderate ectepicondyle that projects approximately 5 cm beyond the lateral condyle. Aside from the massive proportions, the most important feature of the humerus is the fact that the distal extremity is not twisted with respect to the proximal end. The plane of the external and internal condyles, which must be perpendicular to the plane of elbow flexion, is also perpendicular to the axis of the humeral head. This means that the humerus could not have been held in a horizontal attitude, as maintained by Nopcsa (1928b) for *Scolosaurus* and by Russell (1940) for *Edmontonia*. It is quite obvious that the plane of flexion and extension of the elbow is very nearly coincident with the plane of extension and retraction of the humerus in the glenoid. Hence the fore limb could not have functioned in the sprawling manner of a lizard or salamander but must have been maintained in a near vertical or upright position beneath the glenoid.

Both ulnae are preserved in the type specimen, also in AMNH 3035, and in numerous other American Museum and Yale specimens. The ulna (Plate 24: E and F) is very robust proximally with a massive olecranon projecting well above the humeral articular facet. Distally, however, the shaft tapers abruptly and the distal end is rather narrow transversely and of only moderate (10 to 11 cm) longitudinal diameter.

Both radii of the type specimen and that of AMNH 3035, together with several in the Yale collections, reveal this bone as a short, massive and cylindrical bone with broadly expanded, flaring extremities (see Plate 24: G). The shaft is straight and robust. The proximal end flares out abruptly in all directions and terminates in a broad, oval, slightly concave surface. The distal end flares out gradually to a broad, convex articular condyle.

The carpus is not known, but the left manus is represented by five metacarpals, seven phalanges and three poorly preserved hooflike unguals. Data regarding the relationships of these elements are not preserved, and no phalangeal formula can be given. The metacarpals tentatively are identified from shortest to longest as follows: I, II, III, V and IV. Attempts to identify the phalanges on the basis of articular fits suggest that the proximal phalanges of all five digits are present, plus the second phalanges of III and IV. The unguals appear to be those of II, III and IV. If these identifications are correct the phalangeal formula would seem to be 2-3-4-3-2 or 3. The metacarpals are quite massive, except for the first and fifth, but are considerably less massive than the metatarsals. The phalanges are broad but short—sometimes very short. The unguals are broad, flat and bluntly rounded.

Pelvic girdle. The type specimen includes most of both ischia (Plate 25: A, B and

C) and ilia, but the pubes are not preserved. A solitary right pubis (Plate 25: D, E and F) is known (YPM 5141) from Yale locality YPM 63-16, as well as several incomplete ischia (YPM 5101 and 5141 from localities YPM 63-19 and 63-16, and YPM 5513 from YPM 63-20).

The ilia are greatly expanded plates of bone that extended far laterally from the sacrum in a nearly horizontal plane, as in *Nodosaurus, Polacanthus* and presumably all nodosaurs. In the type specimen neither ilium is complete and both are distorted, but the general form corresponds approximately to that figured for *Dyoplosaurus* by Parks (1924). It is best described as a massive, broad, triangular bone, oriented close to the horizontal. It has a short, massive posterior blade and a very long, narrow and thin anterior blade that extends forward, and slightly out and downward. This anterior process apparently conformed to the external body profile (as presumably did the nearly horizontal proximal region of the ilium), because toward the extremity it curves from the horizontal to an inclined plane 30 to 40° from the horizontal. No evidence to this effect is preserved, but presumably this anterior process was contacted by one or more transverse processes of the several dorsosacral vertebrae that fused to the sacrum.

The acetabulum, which is closed, consists of a large, massive, ventrally directed cuplike socket on the underside of the ilium. It is nearly completely surrounded by stout, ventrally projecting walls of bone. The ilia are fused to the sacral vertebrae by four massive sacral ribs that attach in the region of the acetabulum. The region between the acetabulum and the sacral vertebrae is open above (i.e. there is no medial expansion of the ilium) but presumably was covered with dermal scutes. The incomplete left pubis (the posterior blade is missing) measures 87 cm anterior to the center of the acetabulum and approximately 40 cm in width lateral to the center of the acetabulum. The external edge of the left ilium, lateral to the acetabulum, was more than 70 cm from the sagittal plane. The right ilium appears to have had comparable dimensions, the distance between the external margin and the center of the acetabulum is 45 cm, and the length anterior to that center is 90 cm. The length of the right ilium is 129 cm.

The ischium is a relatively stout and long bone, broad and massive proximally and thin and tapered distally. Its precise relationship to the ilium is not known but it apparently articulated with the ventral edge of the massive posterior-internal wall of the acetabulum. The iliac peduncle is very stout and the pubic peduncle is moderately so. Between these peduncles the ischium is deeply concave externally, and a thin bony lamina extends between them. The maximum proximal dimension (longitudinal) is in excess of 25 cm for the right ischium of the type, and more than 23 cm in YPM 5141. The shaft tapers distally to about midlength, at which point the maximum longitudinal dimension is 8.5 cm in the type. Just below midlength the ischium shaft bends strongly downward at approximately 35 to 45° to the proximal shaft and tapers further to 5 cm, just above the very slightly inflated distal extremity. The external surface at midlength is marked by a long flat scar that probably is the origin site of part of the M. pudo-ischio-femoralis. The ischium closely resembles that of *Edmontonia rugosidens* (USNM 11868) figured (as *Palaeoscincus*) by Gilmore (1930) with the exception that the distal third is less tapered and more ventrally deflected in the present species. In longitudinal profile the distal part of the shaft curves inward at about 30° to the proximal part of the shaft, thereby placing the extremity in or near the sagittal plane. Rugose areas on the extremity indicate that the ischia were probably joined by cartilage.

The pubis is known only from a nearly complete right pubis (YPM 5141) that was found closely associated with a right ischium. As in all nodosaurs, the pubis is greatly reduced to a very small triradiate, hook-shaped bone, measuring only 13.5 cm in the present instance. The hooked or downcurved portion is quite massive and rugose and represents the remnant anterior or prepubic blade. Posteriorly a stout, triangular-in-section, rugose articular surface is the ischiac articulation. In the present specimen (YPM 5141) this surface fits the pubic peduncle of the associated ischium almost perfectly (see Plate 25: G). A thin, narrow blade projects dorsomedially and backward from the medial surface of the "prepubic process". This process, which represents the postpubic process, expands into a broad blade distally and extends at least 10 cm caudally. Dorsally a broad rugose area, at right angles to and adjoining the ischiac articular surface, is the articular surface for the ilium. The internal surface, with the exception of the postpubic process, is smooth. The external surface, however, is very irregular and rugose, as are the adjacent surfaces of the ischium. These presumably mark cartilaginous and ligamentous attachments along the inner wall of the acetabulum. Quite obviously the pubes did not meet in the midline, in view of the widely spaced positions of the acetabulae. Aside from the dorsal rugosity mentioned above, there is no clear evidence in presently known *Sauropelta* material as to the nature of the pubis-ilium union, but I suspect that the entire upper margin of the pubis articulated with the ventral edge of the anteromedial wall of the acetabular cup, as seems to have been the situation in *Polacanthus* (BMNH R175), although both the pubis and ischium are of quite different form in *Polacanthus*. The Yale specimen compares almost exactly with that of *Edmontonia rugosidens* (*Palaeoscincus*) illustrated by Gilmore (1930).

Eaton (1960) figured and described a small bladelike bone as the left pubis of *Silvisaurus* on the grounds (in part) that it resembled the pubis of some other ornithischians—*if the postpubic process were removed* (italics mine). This bone resembles much more closely the sternal bone of some ornithopods, particularly that of hadrosaurs (see Lull and Wright, 1942). Russell (1940) described a pair of nearly identical bones in *Edmontonia rugosidens* as clavicles (clavicles have been reported by Brown and Schlaikjer [1940] in *Protoceratops*), although he was unable to show how they articulated. I am inclined to disagree with both identifications because of the resemblance of these bones to ornithopod sternals, plus the fact that Eaton's bone does not resemble in the slightest way any known ankylosaurian pubes. Eaton apparently was misled by Gilmore's figure (1930, fig. 16) of what he interpreted as the right pubis of "*Palaeoscincus*" (= *Edmontonia*), that illustrates the internal side—*not* the external side as stated in the caption. The error in the caption apparently led Eaton to conclude that "Gilmore's bone can hardly be a pubis" because the figure shows a large *lateral* process that Gilmore labeled as a "postpubic process". The supposed lateral position of this bladelike process would have placed it projecting across the acetabulum—an impossible situation. Gilmore's text, however, clearly states that the postpubic process branches off the *internal* surface and extends backward and downward (medial to the acetabulum).

As noted above, Gilmore's specimen is very similar to the pubis described here that was found closely associated with and articulates perfectly with a right ischium. Thus the present material would seem to clear up any question that may have existed regarding the validity of Gilmore's identification. It also suggests that the element described by Eaton as the pubis of *Silvisaurus* probably is not that bone.

Hind limb. Most of the hind limb and pes elements (Plate 26) are known in the type specimen and from isolated elements in the Yale collections. Only the astragalus and calcaneum, a single ungual and the tarsals (if present) are not represented. The femora of the type are long (76 to 77 cm) and quite robust (31.32 cm in minimum shaft circumference) (see Plate 26: A and B). A stout, ellipitical head projects medially from a massive greater trochanter. There is little indication of a distinct lesser trochanter. The fourth trochanter is represented by an elongated, irregular swelling slightly above midlength of the shaft. The most distinctive feature is the very robust form of the distal end of the femur, with large, well-rounded internal condyles. These project far backward and are separated both distally and posteriorly by a deep intercondylar groove.

The tibia (Plate 26: C and D) is similarly robust and long, measuring 57.5 cm (left) in length and more than 26 cm in minimum circumference. The proximal end is greatly expanded in correspondence with the femur (minimum circumference is 67 cm) and the distal end is transversely expanded. The cnemial crest is short and not very prominent. A broad external concavity proximally and a faint flattened surface distally mark the areas of fibula apposition.

The fibula is a slender, slightly curved, compressed cylinder. Neither end is well preserved in the two fibulae of the type but both extremities were expanded. The length of the type right fibula is 55 cm, only slightly shorter than the tibia (57.5 cm) (Pl. 27: A).

As noted previously, the tarsus is not known, but the pes is known from the nearly complete right foot of the type. With the exception of the reduced splintlike fifth metatarsal, the metatarsals are very robust. The third is the longest and the second, fourth and first are progressively shorter in that order. No records are available of the original arrangement of the 12 phalanges preserved, but the arrangement illustrated in Plate 26, as determined by the best articular fit of the various bones, is a reasonable pattern. It indicates a phalangeal formula of 2-3-4-4 or 5-0. The proximal(?) phalanges are the longest and most massive on each digit, with successive phalanges being progressively shorter or more compressed. The unguals are broad, flat, only slightly curved longitudinally and are rounded bones with rugose and irregularly sculptured surfaces. The foot as a unit was short, broad and quite massive, but almost certainly was not plantigrade.

The left foot is also present in the type specimen but very poorly preserved. It consists of five metatarsals, eight phalanges and four unguals. This would seem to confirm a phalangeal formula of 2-3-4-4-0, but it does not eliminate the possibility of five phalanges in the fourth digit. AMNH 3016, which includes parts of both hind feet, suggests that the formula may have been 2-3-4-5-0. The left pes includes five metatarsals, ten phalanges and four unguals, the right pes includes five metatarsals, nine phalanges and three unguals. If none of these are from the manus (and again no quarry data are available to show preserved relationships), then the fourth pedal digit clearly must have had five phalanges. Because no field data exist, this formula must remain as unconfirmed although probable for *Sauropelta*.

Dermal armor. A wide variety of dermal plates, spines, spikes and irregular ossifications are preserved in the type specimen and also in AMNH 3035, 3016, 3033 and

TABLE 5. Principal measurements of *Sauropelta edwardsi.*

		AMNH 3032		AMNH 3035		YPM 5502		YPM 5391		YPM 5141	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Cranial and Mandibular Dimensions											
Skull	length										
	height										
	width			35±							
Maxillary tooth row length											
tooth positions											
Mandible length			—	>38.5	>35		36.7	36.0			
Mandibular tooth row length			23.0	24.0			19.8	21.0			
positions			27	26?			25	26			
Height at coronoid process			—		13		11.6	12.0			
Vertebral Dimensions											
Axis centrum	length			10.5							
	height			6.5							
	width			8.5							
Axis neural spine height				8.3							
Third cervical centrum	length			8.0							
	height			6.5							
	width			8.5							
Third cervical neural spine height				10.5							
Fourth cervical centrum	length			7.5							
	height			7.0							
	width			9.0							
Fourth cervical neural spine height				11.5							
Fifth cervical centrum	length			8.0							
	height			6.5							
	width			9.5							
Fifth cervical neural spine height				—							

Sixth cervical			—
Seventh cervical			—
Dorsal "A" centrum	length*	9.2	
"A"	height	—	
"A"	width	—	
"B"	length	9.0	
"B"	height	10.0	
"B"	width	8.0	
"C"	length	9.0	
"C"	height	9.8	
"C"	width	7.5	
"D"	length	9.0	
"D"	height	10.0	
"D"	width	8.0	
"E"	length	9.0	
"E"	height	10.0	
"E"	width	7.8	
"F"	length	9.5	
"F"	height	9.5	
"F"	width	7.8	
"G"	length	9.0	
"G"	height	10.7	
"G"	width	7.5	
"H"	length	9.0	
"H"	height	10.0	
"H"	width	8.5	
"I"	length	9.5	
"I"	height	10.0	
"I"	width	9.0	
"I" neural spine height		19.5	
"J" centrum	length	9.5	
"J"	height	9.5	
"J"	width	8.5	
"K"	length	9.5	
"K"	height	10.5	

TABLE 5. (continued)

		AMNH 3032		AMNH 3035		YPM 5502		YPM 5391		YPM 5141	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
"K"	width	9.5									
"L"	length	9.5									
"L"	height	9.5									
"L"	width	9.0									
"M"	length	9.5									
"M"	height	10.0									
"M"	width	9.0									
Caudal "A"	length	9.0									
"A"	height	8.5									
"A"	width	12.0									
"A"	neural spine height	16.0									
"E"	centrum length	7.0									
"E"	height	9.0									
"E"	width	10.5									
"E"	neural spine height	15.0									
"J"	centrum length	7.0									
"J"	height	9.0									
"J"	width	10.0									
"J"	neural spine height	13.5									
"O"	centrum length	8.0									
"O"	height	8.3									
"O"	width	9.0									
"O"	neural spine height	9.5									
"T"	centrum length	8.0									
"T"	height	6.3									
"T"	width	6.5									
"T"	neural spine height	—									
"Y"	centrum length	7.0									
"Y"	height	4.5									
"Y"	width	4.5									

"Y" neural spine height	—
"DD" centrum length	6.0
"DD" height	—
"DD" width	—
"II" length	—
"II" height	—
"II" width	—

Pectoral Girdle and Fore Limb Dimensions

Scapula	length				
	distal width				
	proximal width				
Coracoid length					
height					
Humerus	length	55.0	59.0	56.5	—
	proximal length	13.0	12.0	23.5	—
	distal width	23.0	21.0	24.0	—
Deltopectoral crest length		—	—	—	—
Humerus minimum circumference		25.5	—	24±	—
Ulna	length	46.0	43.0	48.5	49.0
	proximal width	20.0	19.0	19.0	18.2
	distal width	10.5	11.0	9.0	10.0
Radius	length	39.5	35.0±	—	—
	proximal width	13.0	13.5	—	—
	distal width	12.5	12.0	—	—
Metacarpal I length		?10.5	—	?9.8	—
II		?11.0	—	?11.0	—
III		?12.5	—	?11.5	—
IV		?14.5	—	?12.0	—
V		?14.0	—	—	—

TABLE 5. (continued)

		YPM 5456		YPM 5459		OU 11		PU 16338		AMNH 3040		BB 1	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Pelvic Girdle and Hind Limb Dimensions													
Ilium length			139.0±	130±									—
Ischium	length (shortest)		59.0	—									>54.0
	proximal width		25.5	—									>22.0
	distal width		7.5	—									—
Pubis length													15.0
height													10.5
Femur	length		77.0	76.0									
	proximal width		27.0	27.5									
	distal width		23.3	23.0									
Tibia	length		57.5	55.0									
	proximal width		25.0	26.0									
	distal width		23.5	24.5									
Fibula	length		—	—									
	proximal width		—	—									
	distal width		—	—									
Metatarsal	I length		—	?12±									
	II		—	?16.5									
	III		—	?18.5									
	IV		—	?15.5									
	V		—	—									

All measurements in centimeters.

* Real segment numbers are unknown, hence all dorsals and caudals are designated by letter. (Every fifth segment listed.)

? = Identity of element is uncertain.

± = Approximate.

5853, as well as numerous isolated elements from a large number of Yale sites (see Plate 27). These vary from small, circular to oval, flat or slightly curved plates to larger, oval, keeled plates, to triangular and strongly bladed or spined, or long thin, sharp-crested blades with narrow elliptical bases. A few solid, oval to round-in-section spikes—perhaps caudal spikes—are also known. All except the latter spikes show some degree of external rugosities or irregular sculpture, as though they had been covered in life by horny scutes. With the exception of the smallest oval, flat plates, all have distinctly concave to deeply hollowed inferior surfaces. This is most pronounced in the high and narrow, sharp-crested blades.

The arrangement of the various dermal ossifications is not entirely known, but it is preserved in part in AMNH 3035 and 3036. These specimens show that at least portions of the shoulders, back and flanks were veneered with a mosaic of scutes, plates, spines and ossicles. The main plates and spines seem to have been arranged in transverse rows, with flat- or low-keeled plates near the midline and progressively more strongly keeled and spined plates situated laterally. Some fusion of adjacent plates is known, but the interspaces between major plates or spines appear to have been occupied by medium (4 to 5 cm) to small (1 cm) plates and irregular ossicles. The arrangement of the long shoulder spines in AMNH 3035 is in contrast to that shown by Brown (1908) for *Ankylosaurus* (= *Palaeoscincus*). In the latter, Brown reconstructed several shoulder spikes as pointing forward and outward. In AMNH 3035, comparable spikes point out, or backward and out—but none point forward. (The same is true of the shoulder spines of *Phrynosoma, Zonurus* and *Moloch* illustrated for comparison with *Palaeoscincus* by Matthew, 1922.) I suspect that the pattern of AMNH 3035 is correct. Forward-directed shoulder spikes surely would have snagged on brush and tree trunks and therefore would seem an improbable arrangement.

In most details the various dermal plates of *Sauropelta* resemble those of *Nodosaurus, Edmontonia, Ankylosaurus, Hierosaurus, Stegopelta* and *Hoplitosaurus*, as well as those of *Polacanthus*. However, the present materials are less massive and considerably more concave or hollowed in the basal surfaces than are those preserved in these genera.

DISCUSSION: The present state of our knowledge of the Ankylosauria is very poor, and a modern systematic study is sorely needed. A large number of species have been proposed, most on very incomplete (and probably inadequate) material. In the following discussion comparisons are made with several of these taxa, but with the exception of *Hoplitosaurus* I have made no judgment as to their validity; ankylosaurian systematics is outside the scope of this paper.

It is obvious that the suborder as a whole was extremely conservative. The dermal armor, the morphology of the pelvic and pectoral elements, the form of cervical, dorsal and caudal vertebrae and the general design of the skull, jaws and dentition are very similar in all forms. The most aberrant species, perhaps, is *Silvisaurus condrayi.* This conservatism, together with the rarity of complete specimens, will make any analysis of ankylosaurian systematics very difficult.

Among North American ankylosaurs, *Silvisaurus* (Dakota), *Hoplitosaurus* (Dakota?) *Stegopelta landerensis* (Thermopolis) and *Sauropelta* (Cloverly) are the earliest known representatives. *Nodosaurus textilis* may also be of Early Cretaceous age, from either the "Dakota" Sandstone or the Thermopolis or Mowry Shales east of

Como Bluff, Wyoming, but the precise location and stratigraphic level have been lost. *Polacanthus, Hylaeosaurus* and *Polacanthoides* of the Wealdon are the earliest known European ankylosaurs. All other ankylosaurs apparently are of Late Cretaceous age. *Silvisaurus* is clearly distinct from all nodosaurs in its small form, tapered skull, premaxillary teeth, long mandibular tooth row, depressed position of the orbits, covered lateral temporal fenestra, the form of dermal scutes and spines, and the unfused ribs and dorsal vertebrae.

The type (and only known) specimen of *Hoplitosaurus*, from an uncorrelatable stratigraphic horizon of restricted exposure in Calico Canyon near Buffalo Gap, South Dakota (the same site that produced *Camptosaurus depressus*, USNM 4753, mentioned on page 00), in my opinion is completely inadequate and not diagnostic in any way. However, there are some differences that set *Hoplitosaurus* apart from *Sauropelta*. The femur of *Sauropelta* is at least one third longer than that of *Hoplitosaurus*, yet is less massive. The greater trochanter extends to a level even with the proximal level of the head in *Sauropelta*, and the lesser trochanter is represented by a low crest rather than a distinct process as in *Hoplitosaurus*. Also, the distal condyles are much larger and project further backward in the present material. The distal end of the humerus of *Hoplitosaurus* is not well preserved, but it appears to be far less robust than that of *Sauropelta* and the condyles far less rounded. The solitary anterior caudal vertebra present in the *Hoplitosaurus* type does not correspond to any of those of the *Sauropelta* type (AMNH 3032). Centrum height is greater than width, it differs markedly in end view outline, the neural arch is relatively lower and the neural spine curves up and back (anterior margin is convex). The dermal scutes and spines are generally similar to those of *Sauropelta*, except that all appear to be more massive and only three show even moderately concave inferior surfaces. None show the strongly hollowed bases characteristic of most *Sauropelta* scutes.

These differences may not be great, but in view of the extremely fragmentary nature of the type specimen of *Hoplitosaurus*, it is impossible to define this genus. In my opinion *Hoplitosaurus marshi* is a *nomen dubium*.

Until a thorough systematic analysis of the Ankylosauria is available, assignment of *Sauropelta* must be considered as tentative. Present classifications generally agree on a dual subdivision of the suborder into the primitive Acanthopholidae and the more advanced Nodosauridae (= Ankylosauridae of Brown, 1908). Some of the characters usually cited for the Acanthopholidae are:

Skull small and high, lateral temporal opening present but reduced, no preorbital fenestra, occipital condyle deflected slightly downward, dermal covering thin, snout tends to be narrow, no predentary, mandibular tooth row long, upper tooth row with premaxillary teeth. Neck moderately long, atlas and axis unfused, dorsal ribs not fused to vertebrae, caudal series unarmored, and chevrons not fused to centra. Ilium with long preacetabular process, pubis somewhat reduced, acetabulum usually open and femur slender. Body tends to be high and narrow and dermal armor thin, not coalesced, and rarely fused with ilium, ribs and vertebrae.

With a few exceptions, these characters are true of *Sauropelta*. The most important features would seem to be the very long mandibular tooth row (which we have seen in *Silvisaurus* is matched by premaxillary teeth above), the unfused atlas-axis, the failure of ribs and vertebrae to fuse, the long form of the femur, and the thin, unfused nature of the dermal armor. Accordingly, *Sauropelta* has been referred to the Acanthopholidae. For the same reasons, I believe that *Silvisaurus* should also be referred to this family. Eaton (1960) noted that "*Silvisaurus* may be little changed anatomically from the Old World acanthopholids . . .", but he preferred to assign his new genus to the more universally distributed Nodosauridae. I prefer to extend the range of the Acanthopholidae to the New World and to refer to it both *Silvisaurus condrayi* and *Sauropelta edwardsi.*

5. FAUNAL COMPARISONS

There are relatively few terrestrial vertebrates known from the Lower Cretaceous of North America. Prior to this study, published reports were available on fragmentary vertebrate fossils from the Arundel Formation of Maryland, the Trinity Formation of Oklahoma and Texas, the Lakota(?) of South Dakota, the Dakota of Kansas and the Kootenai of Montana. The Arundel and Trinity Formations have produced more than one or two taxa and will be considered in some detail here. The other three formations require only a few remarks as only one or two vertebrate specimens have been reported to date.

Eaton (1960) described a partial skeleton of a primitive ankylosaur from the Terra Cotta Clay Member of the Dakota Formation of central Kansas. This specimen (UKM 10296), *Silvisaurus condrayi*, differs from *Sauropelta* in size, vertebral, mandibular and dental morphology and in the dermal armor. While I consider them distinct, both *Silvisaurus* and *Sauropelta* are primitive and probably are closely related. The fact that *Silvisaurus* has a longer tooth row than *Sauropelta*, extending almost to the symphysis, suggests that it is more primitive but not necessarily of greater age than *Sauropelta*.

Olson (1960) reported a pair of incomplete mandibles from the Kootenai of southwestern Montana (*Toxolophosaurus cloudi*) which he identified as a trilophosaurid protorosaur. Nothing comparable to this has been recovered so far from the Cloverly Formation. The only other vertebrate remains that I am aware of from the Kootenai is a partial skeleton of an ankylosaur collected by Barnum Brown near Great Falls, Montana. This specimen (AMNH 3075) has not been described, but personal examination has led me to conclude that it is quite inadequate and cannot be positively referred to any presently known ankylosaur. It may be another specimen of *Sauropelta*, but there is no dependable anatomical evidence. Consequently there is no reliable vertebrate evidence to support equation of the Cloverly of northern Wyoming and the Kootenai of central Montana. They may, at least in part, be equivalent, but more data are required.

Two very fragmentary specimens were reported (Lucas, 1901, 1902; Gilmore, 1909) from a single locality in Calico Canyon, near Buffalo Gap, South Dakota. The horizon has been considered of questionable Dakota age. One specimen (*Hoplitosaurus marshi*, USNM 4752) has been described by Gilmore (1914) as a scelidosaurid (Stegosauria), but Romer (1956, 1966), Huene (1956) and Lapparent and Lavocat (1955) consider it a nodosaurid (Ankylosauria). There can be little doubt that it is of ankylosaurian rather than stegosaurian affinity. However, the specimen is quite inadequate as a type specimen and could be referred to almost any ankylosaurian genus.

It appears to be distinct from *Sauropelta*, but I nevertheless consider *Hoplitosaurus* a *nomen dubium*.

The second specimen from Calico Canyon (*Camptosaurus depressus*, USNM 4753) is also very fragmentary. As I have commented elsewhere in this report, *C. depressus* may be a valid taxon. It clearly is distinct from *Tenontosaurus tilletti* and may well be distinct from Morrison species of *Camptosaurus*. With such fragmentary specimens it is impossible to make meaningful assessments as to affinities with Cloverly taxa. Certainly there is no reliable evidence here for equating the Calico Canyon stratum with the Cloverly Formation to the west.

These reports constitute the published record of Early Cretaceous vertebrate remains from the western interior with which the Cloverly fauna might be compared.

ARUNDEL FORMATION, MARYLAND

The first published records of fossil vertebrate remains from the Arundel Formation were those of Johnston (1859) and Leidy (1865). They were followed by studies by Marsh (1888, 1896b), Hay (1908), Lull (1911a, 1911b) and Gilmore (1920, 1921). Although the Arundel collections included more than 100 specimens, they consist entirely of isolated teeth, bones or fragments. Hatcher reported that "no two bones or fragments of all that material collected from the Potomac beds [Arundel Formation] in Maryland were found in such relation to one another as to demonstrate that they belonged to the same individual. . . . the scattered and disarticulated state in which [they were] found, must be constantly borne in mind." (Quoted by Gilmore [1921, p. 582].)

The fragmentary nature of the Arundel specimens has been a major source of difficulty in interpreting this fauna and is the principal reason why the Arundel and Cloverly faunas cannot be positively equated. The lists given below illustrate the diverse interpretations of Marsh, Lull and Gilmore of the Arundel vertebrate fauna. It is not appropriate to review here the details of these interpretations or the collections on which they are based. They have been amply expressed by Lull (1911a, 1911b) and Gilmore (1920, 1921). Although I am inclined to disagree with some of the synonymies adopted by Gilmore (ie, *Pleurocoelus* = *Astrodon*) on the basis that there is insufficient evidence, I will use the faunal list given by Gilmore (1921) in the remarks that follow.

SAUROPODA: With the exception of several small (10 cm long) pleurocoelus vertebrae, the limited postcranial sauropod remains recovered from the Cloverly Formation do not compare closely with the few comparable elements from the Arundel Formation. The Cloverly material is clearly from a much larger animal than any represented in the Arundel collections. For example, the type tibia of *Astrodon altus* (USNM 4971), the larger of the two species established by Marsh (1888) in the Arundel, is one third shorter than the tibia (YPM 5450) that we collected at Crooked Creek (63.5 cm vs 98.5 cm), (compare Plate 14: B with Plate XVIII, fig. 3 of Lull, 1911b). The dorsal vertebrae collected by us are considerably larger than any from the Arun-

Vertebrate Fauna of the Arundel Formation

Listed by Marsh, 1888	Listed by Lull, 1911	Listed by Gilmore, 1921
SAUROPODA	SAUROPODA	SAUROPODA
Pleurocoelus nanus	*Pleurocoelus nanus*	*Astrodon nanus*
Pleurocoelus altus	*Pleurocoelus altus*	*Astrodon altus*
	Astrodon johnstoni	*Astrodon johnstoni*
THEROPODA	THEROPODA	THEROPODA
Allosaurus medius	*Allosaurus medius*	*Dryptosaurus? medius*
Coelurus gracilis	*Coelurus gracilis*	*Coelurus gracilis*
	Creosaurus potens	*Dryptosaurus? potens*
		Ornithomimus affinis
?	ORTHOPODA	ORTHOPODA
Priconodon crassus	*Priconodon crassus*	*Priconodon crassus*
	Dryosaurus grandis	
CROCODILIA	CROCODILIA	CROCODILIA
	Goniopholis affinis	*Goniopholis affinis*
TESTUDINATA	TESTUDINATA	TESTUDINATA
	Glyptops caelatus	*Glyptops caelatus*

del; the latter, which consist only of centra, are also too incomplete to be compared adequately with the Cloverly specimens.

In contrast to the postcranial material, sauropod teeth from the Cloverly Formation compare very closely with teeth from the Arundel Formation. Both formations have yielded only nonspatulate, simple cylindrical cones slightly compressed, curved and twisted—the so-called *Astrodon*-type of tooth. Most of the small sauropod teeth from the Arundel have been referred to *"Pleurocoelus"* (*Astrodon nanus* in Gilmore's list) because they are smaller than the very similar type specimen of *Astrodon johnstoni*. No teeth are represented among the type materials of *Astrodon nanus*, but it is obvious that the size differences could be ontogenetic. Compare the type of *Astrodon johnstoni* in Plate 14: E with a typical *"Pleurocoelus"* (= *Astrodon nanus*) tooth shown in Plate 14: F. Collections from the Cloverly include both large and small teeth that are remarkably similar to the type of *Astrodon johnstoni* and to the smaller teeth referred to *"Pleurocoelus"* or *Astrodon nanus*.

It would appear from the dental evidence that one or more rather closely related species of sauropod existed during Arundel and Cloverly times. The postcranial material does not contradict this, but the available material simply is not comparable.

THEROPODA: Gilmore recognized four theropod species in the Arundel fauna. All four are based on extremely fragmentary remains that are impossible to compare adequately with our Cloverly collections. *Dryptosaurus? medius* is based on a single tooth (USNM 4972), *Dryptosaurus? potens* on a single dorsal centrum (USNM 3049), *Coelurus gracilis* on an ungual phalanx (USNM 4973) and *Ornithomimus affinis* on an astragalus, fragments of metatarsals II and III and five phalanges (USNM 5652, 5704, 5684, 5453, 6108, 5703, 8456 and 6107). The latter cotypes had been used by Marsh (1888) in founding *Allosaurus medius* and subsequently were referred by Lull (1911b) to his ornithopod species *Dryosaurus grandis* (leaving only the tooth, USNM 4972, as the type of *A. medius*). Gilmore (1920) established the ornithomimid affinities of these foot bones.

In summary, the Arundel Formation contains one and perhaps two species of large theropod, one small theropod species and one ornithomimid. The Cloverly Formation contains at least one large theropod species (undefinable), one small theropod (*Deinonychus*), one very small theropod (*Microvenator*) and an undefinable ornithomimid. *Coelurus gracilis* would appear to have been intermediate in size between *Microvenator* and *Deinonychus*. The ungual morphology is quite similar to that of the manual unguals of the latter (compare Plate 110, fig. 1 of Gilmore, 1921 with Plate 10: M of this report). On the basis of the metatarsal fragments, *Ornithomimus affinis* was slightly larger than the Cloverly ornithomimid (see Plate 11: F, G and H compared with Gilmore's Plate 113, fig. 3 and Plate 114, fig. 1).

ANKYLOSAURIA: A number of ankylosaur teeth, including a worn tooth that is the type of *Priconodon crassus* (USNM 2135), have been found in the Arundel. The number is small and most are stream abraded. Lull and Gilmore agreed that these closely resembled the teeth of *Palaeoscinus*.

These teeth do not differ significantly from those of *Sauropelta edwardsi* of the Cloverly Formation. However, the similarity does not necessarily indicate close affinities, for dental morphology in the Ankylosauria appears to have been quite conservative. It does, however, establish the presence of this group in both faunas (see Plate 22: D, E and F here and Plate XX, fig. 5 of Lull, 1911b).

CROCODILIA: Lull (1911b) established a new species of crocodile, *Goniopholis affinis*, designating a single tooth (USNM 8452) as the type specimen after comparison with teeth from the Morrison Formation that were then referred to *Goniopholis felix*. Gilmore doubted the generic assignment of such meager materials.

The conical crocodilian teeth from the Cloverly Formation have the same ridged and grooved enamel that is characteristic of those from the Arundel and that appear to be characteristic of all "goniopholids". Beyond indicating the presence of what could be similar crocodilians in both faunus, these remains have no real significance.

CHELONIA: Turtle remains from the Arundel Formation consist of two fragmentary specimens, including the type (USNM 1930) of *Glyptops caelatus*. Perhaps the most significant fact about this specimen is the absence of *Naomichelys* type of pustulose ornamentation.

DISCUSSION: Although it cannot be established that there are any species or genera that are common to the Arundel and Cloverly faunas, it is evident, even from these fragmentary remains, that there is striking similarity between the two. Perhaps the most important similarities are in the "*Astrodon*"-toothed sauropods, the ornithomimids, and the ankylosaurs. These similarities may be more apparent than real, but this is the hazard of working with such limited evidence. The faunal similarities may also be more ecologic than chronologic, except for the fact that the most common element of the Cloverly fauna is not represented in the Arundel collections. Not a single scrap is known of an ornithopod in the Arundel collections—now that Gilmore has shown Lull's *Dryosaurus grandis* to be an ornithomimid. *Tenontosaurus* is such an important element of the Cloverly fauna that absence of all ornithopods from the Arundel must have particular significance if the faunal similarities cited above are real.

TRINITY FORMATION, TEXAS AND OKLAHOMA

Work is currently under way by B. H. Slaughter of Southern Methodist University on the terrestrial fauna, particularly the microvertebrate fauna, of the Trinity Formation. The following remarks do not include data from Slaughter's studies, most of which are not yet published. My comments are restricted to the few published records and to two undescribed specimens, one in the collections of the J. Willis Stovall Museum of Science at the University of Oklahoma and the other at the Field Museum in Chicago.

Unfortunately, the published data have little or no relevance to the Cloverly fauna as it is presently known. S. W. Williston (*in* Larkin, 1910) described a right coracoid of an unidentifiable sauropod from near Caddo, Oklahoma and Stovall and Langston (1950) described two partial skeletons of a large theropod, *Acrocanthosaurus atokensis* from Atoka County, Oklahoma. The sauropod coracoid is not comparable to sauropod remains from the Cloverly. On the other hand, at least one large theropod is present in the Cloverly fauna, as shown by the large tooth (YPM 5377) illustrated in Plate 20: N, and the unusual dorsal vertebra (YPM 5285) reconstructed in Figure 6. The vertebral series of *Acrocanthosaurus* is not fully known, but the greatly elongated neural spines of the known dorsals of the Trinity species are totally unlike the short, wedge-shaped neural spine of YPM 5285. Thus we may safely conclude that the two are quite distinct.

The only other Trinity vertebrates reported to date are mammals and, in view of the fact that mammals are not yet known from the Cloverly, of little value in faunal comparisons.

The only reason for comparing the Trinity fauna with that of the Cloverly is the existence of the two undescribed specimens mentioned earlier. The first is a nearly complete and uncrushed skull of a medium-sized ornithopod that appears to be referable to *Tenontosaurus tilletti*. This specimen (OU 8-0-S2) is presently being studied by Dr. Wann Langston. The second specimen is a remarkably complete turtle that appears to be referable to *Naomichelys*. This specimen is in the Field Museum collections (FMNH PR-273). I have examined both specimens, and there is little doubt in my mind that both are very close to, if not conspecific with, the Cloverly specimens. Final assessment, however, must wait for detailed studies of these two specimens.

Despite that fact that the Trinity fauna is presently known from fewer taxa than the Arundel fauna, there is significant unpublished evidence that the Trinity and Cloverly faunas may be contemporaneous.

WEALDEN BEDS, EUROPE

A thorough analysis of the vertebrate fauna of the Wealden of western Europe is beyond the scope of this report. Consequently, the following comparison of the Wealden and Cloverly faunas must be considered with certain facts in mind. First, with the exception of the multiple, articulated skeletons recovered at Bernissart, most of the Wealden taxa have been proposed on the basis of very fragmentary remains (even solitary bones and teeth). Second, a considerable bibliography has developed over the last century relating just to questions of taxonomy and synonymy regarding these classic Wealden fragments. Third, although most fossil vertebrate remains from the Wealden have been recovered from relatively few locales (on both sides of the English Channel), the stratigraphic relationships of these sites have not been established. For example: the stratigraphic relationships between the classic British localities on the Isle of Wight (that produced *Hypsilophodon* among other things) and the *Iguanodon* coal mines at Bernissart, Belgium, are quite unknown. In view of the fact that so many of the Wealden taxa are based on such fragmentary specimens, and considering the unresolved problems of synonymy, I am restricting my comparison with Cloverly taxa to very general observations. It is appropriate to make these comparisons in spite of the difficulties because the Wealden and the Cloverly are the two most productive terrestrial formations of Early Cretaceous age.

The following lists include the major elements of the Wealden vertebrate fauna. They are not exhaustive lists, and no doubt a number of species have been omitted. Time simply did not permit further search. Because we found no mammals or amphibians in the Cloverly Formation, those groups will not be discussed further.

SAUROPODA: The following species have been proposed for presumed sauropod remains from the Wealden:

Cetiosaurus brevis Owen, 1842
Cetiosaurus conybeari Melville, 1849
Pelorosaurus conybeari Mantell, 1850
Pelorosaurus becklesii Mantell, 1852
Ornithopsis hulkei Seeley, 1870
Bothriospondylus elongatus Owen, 1875
Bothriospondylus magnus Owen, 1875
Chondrosteosaurus gigas Owen, 1876
Ornithopsis eucamerotus Hulke, 1882a
Pleurocoelus valdensis Lydekker, 1890
Titanosaurus valdensis Huene, 1929a

Cetiosaurus brevis was originally based on three dorsal and caudal vertebrae. These clearly are not sauropod but *Iguanodon*, probably *I. bernissartensis.* Four referred caudals (BMNH 2544-2550), which are sauropod, were made the new type of *C. brevis*—a procedure that I consider impossible. Melville (1849) subsequently designated the same four caudals as the type of *C. conybeari.* In the following year, Mantell (1850) referred these vertebrae to his *Pelorosaurus conybeari* which he had based on a large humerus (BMNH 28626). In 1852, Mantell proposed a new species, *Pelorosaurus becklesii,* on the basis of a short, stout sauropod humerus (BMNH R-1868). The distinct differences between the long, slender humerus of *P. conybeari* and the short, stout humerus of *P. becklesii* clearly establish the presence of two sauropod species in the Wealden. The former may be a brachiosaurid, the latter appears to be a titanosaurid. An interesting, and complicating, fact is that Mantell (1850) indicated that the type caudals of *C. conybeari* (BMNH 2544-2550) came from the same quarry in the Tilgate Forest, at Cuckfield, Sussex as the type humerus of *P. conybeari.*

The type of *Ornithopsis hulkei,* a dorsal vertebra (BMNH 28632), appears to be brachiosaurid and may belong to the same species as the slender type humerus of *P. conybeari. Bothriospondylus elongatus* is based on a single, long, pleurocoelous dorsal centrum (BMNH 2239) which is not diagnostic. *Bothriospondylus magnus* is based on the type vertebra of *Ornithopsis hulkei* (BMNH 28632) and, as noted above, is perhaps referable to *Pelorosaurus* and appears to have brachiosaurid affinities. The two type cervicals of *Chondrosteosaurus gigas* (BMNH 46869, 46870), which may not belong to the same individual, are poorly preserved but appear closer to titanosaurids than to brachiosaurids. The type pubis and ischium (BMNH R97) of *Ornithopsis eucamerotus* may belong to one of the previously described Wealden species, but this cannot be demonstrated with present material. The pubis is similar to that of *Titanosaurus,* but the ischium is unique. It is a deep blade with a very sharp, caudally directed curve at about midlength. This curve along the posterior margin approximates 70° and is greater than in any other sauropod ischium that I am aware of. *Pleurocoelus valdensis* is based on a single tooth that is remarkably similar to those from the Arundel and Cloverly Formations, but little can be said about its true affinities. *Titanosaurus valdensis* is based on a single, very procoelous caudal vertebra (BMNH R151) that strongly suggests titanosaurid affinities.

For the most part these type sauropod specimens from the Wealden do not compare closely with any of the Cloverly specimens. For example, the type humerus of *Pelorosaurus conybeari* is of much more slender construction than that of the Cloverly sauropod (YPM 5452, see Plate 14: C), and that of *Pelorosaurus becklesii* is much too small. The ischium of *Ornithopsis eucamerotus* is not comparable to the Cloverly ischia (YPM 5449). Lydekker's "neotype" caudals of *Cetiosaurus brevis* (= *Cetiosaurus conybeari,* BMNH 2544-2550) are similar to two anterior caudals (YPM 5199, 5104) collected at Crooked Creek (Locality YPM 63-19) in Wyoming, but are slightly more procoelous. Only the numerous "*Pleurocoelus*" or *Astrodon*-like teeth from the Wealden compare closely with any sauropod remains from the Cloverly Formation. Some are indistinguishable from Cloverly specimens. Unfortunately, this evidence can not be assessed in terms of systematic relationships at the present time. It appears that only the "*Pleurocoelus*" or *Astrodon* kind of sauropod teeth are known from Cretaceous strata; *Camarasaurus* or *Apatosaurus* teeth are unknown.

THEROPODA: The following species of Theropoda have been proposed, based on various specimens, from the Wealden of the British Isles:

Calamospondylus oweni Fox, 1866
Poikilopleuron pusillus Owen, 1876
Thecospondylus horneri Seeley, 1882

Megalosaurus dunkeri Dames, 1884
Aristosuchus pusillus (Owen), Seeley, 1887
Thecospondylus daviesi Seeley, 1888
Calamospondylus foxii Lydekker, 1889g
Megalosaurus oweni Lydekker, 1889b

Calamospondylus oweni and *Poikilopleuron pusillus* were based on the same specimen, five sacral vertebrae and part of the pelvis (BMNH R178). In 1887 Seeley made *Poikilopleuron pusillus* the type of his new genus *Aristosuchus. Thecospondylus horneri* is based on the natural cast of a sacral vertebra (BMNH R291) and is of indeterminate nature. *Thecospondylus daviesi* was established for two cervical vertebrae (BMNH R181). These vertebrae have been referred to *Coelurus* but subsequently were made the type of a new genus, *Thecocoelurus*, by Huene (1923). *Calamospondylus foxii* is based on two other very similar cervical vertebrae (BMNH R901). Lydekker later (1891) proposed the name *Calamosaurus* when he discovered that *Calamospondylus* was preoccupied. *Thecocoelurus daviesi* and *Calamosaurus foxii* may very well be synonyms, in view of the very similar form and size of the type cervicals of each. The fact that the two type specimens do not include a common segment makes formal action to this effect unwise. It is also my opinion that *Aristosuchus pusillus* (= *Poikilopleuron pusillus* = *Calamospondylus oweni*) probably belongs to the same species. Thus, it is quite possible that only a single species of small theropod is represented among all the fossil vertebrate remains presently known from the Wealden Beds. These do not compare closely with any of the small theropods from the Cloverly Formation (i.e., *Deinonychus* or *Microvenator*). The pubis of *Aristosuchus pusillus* (BMNH R178) appears to be the same size as that of *Coelurus fragilis* (YPM 2010), but differs from that species in the nearly straight inferior margin of the expanded distal pubic foot, compared with the strongly curved inferior pubic margin in *Coelurus.* The vertebrae also compare closely in both form and size to those of *Coelurus fragilis* (YPM 2010) from the Morrison Formation of southern Wyoming.

Two species of large theropods have been proposed for Buckland's (1824) genus *Megalosaurus* (which is from the Stonesfield Slates rather than the Wealden). *Megalosaurus dunkeri* was based on a single tooth and *M. oweni* on three metatarsals (BMNH 2559). The latter was originally figured by Owen (1872) as *Hylaeosaurus,* but Hulke (1881) noted its distinctive form and Lydekker (1889b) assigned it to *Megalosaurus.* These remains, plus additional referred materials, show the presence of at least one species of large theropod in the Wealdon. These remains have been referred to *Altispinax* by Huene (1923), which he characterized by very high-spined dorsal vertebrae. If correctly referred to *Altispinax*, then the Wealden species do not compare at all with the solitary low-spined vertebra (YPM 5285, see Fig. 6) from the Cloverly Formation.

ORNITHOPODA: Ornithopods seem to be the best represented and most studied elements of the Wealden fauna. The following list summarizes the various ornithopod species that have been proposed for Wealden specimens:

Iguanodon anglicum Holl, 1829
Iguanodon mantelli Meyer, 1832

Streptospondylus major Owen, 1842
Cetiosaurus brevis Owen, 1842
Cetiosaurus brachyurus Owen, 1842
Streptospondylus recentior Owen, 1851
Stenopelix valdensis Meyer, 1859
Hypsilophodon foxii Huxley, 1870a
Vectisaurus valdensis Hulke, 1879
Iguanodon bernissartensis Boulenger, 1881
Iguanodon seeleyi Hulke, 1882b
Sphenospondylus gracilis Lydekker, 1888a
Iguanodon dawsoni Lydekker, 1888a
Camptosaurus valdensis Lydekker, 1889d
Iguanodon fittoni Lydekker, 1889c
Iguanodon hollingtoniensis Lydekker, 1889c
Iguanodon atherfieldensis Hooley, 1925

With the exception of *Stenopelix valdensis,* I have seen the type specimens of all of these species as well as numerous other referred specimens. I have also studied the wax impression molds of parts of the type specimen of *Stenopelix valdensis* that are currently housed in the collections of the Humboldt Museum in East Berlin. Although the 17 species were purportedly collected from the "Wealden" Beds, not all were recovered from the same stratigraphic level. Nevertheless it is extremely improbable that such a large number of ornithopod species existed in western Europe during Wealden time.

The nomenclature of Wealden ornithopods is in a chaotic state to say the very least, yet materials do exist for resolving at least part of the present chaos by means of modern multivariate analyses. The numerous specimens that have been referred to various species of *Iguanodon*, or to some other relatively large ornithopod species, indicate that the Wealden fauna included at least one, and possibly two species of *Iguanodon.* One was large and robust and is typified by most of the specimens recovered from the Bernissart coal mine and now on exhibit in the Royal Institute of Natural Science in Brussels. For the moment we may label this animal as *Iguanodon bernissartensis*, as proposed by Boulenger in 1881. A second species, of smaller and more slender stature, may best be represented by the solitary skeleton (IRSNB 1551), currently referred to *I. mantelli*, or the slightly larger type skeleton of *I. atherfieldensis* (BMNH R5764). One or both of these latter two specimens may represent female specimens of *I. bernissartensis*, but a thorough biometric analysis is required before this can be evaluated. If such studies were to show that the morphologic differences between *I. atherfieldensis* (BMNH R5764) or *I. mantelli* (IRSNB 1551) and *I. bernissartensis* were probably sexual differences, *Iguanodon mantelli* would have priority. However, the name *Iguanodon* is based on the teeth described by Mantell (1825) and Mantell failed to supply a species name. Meyer's (1832) species *"I. mantelli"* was preceded by a brief description of Mantell's "type" teeth (BMNH 2392) by Holl (1829), in which he proposed the name *Iguanodon anglicum.* Thus, if it were to be established that only a single species of *Iguanodon* was represented in the Wealden, according to the rules of priority, *Iguanodon anglicum* would be the valid name.

At this point, it is important to note that no less than 13 of the 17 "species" listed above could belong to just a single species of *Iguanodon.* After careful examination of the type specimens (all of which are in the British Museum, with the exception of *I. bernissartensis*), I believe the type specimens of *I. anglicum*, *Streptospondylus major*, *"Cetiosaurus" brevis* (BMNH 2544-2550), *Streptospondylus recentior*, *Iguanodon bernissartensis* and *Iguanodon atherfieldensis* probably represent remains of a single species. This conclusion has been reached with full awareness of the taxonomic problems raised (for example, *Streptospondylus major* and *Streptospondylus recentior* are both based on the same solitary cervical vertebra [BMNH 2116]). I have chosen not to try to resolve such matters here. A possible second species of *Iguanodon* may be represented by the fragmentary remains from the lower Wealden Wadhurst Clay, presently recognized in the type specimens of *Iguanodon dawsoni* (two dorsal and one caudal vertebrae; BMNH R798), *I. fittoni* (a left ilium; BMNH R1635) and *I. hollingtoniensis* (a right femur; BMNH R1148). *Sphenospondylus gracilis* (BMNH 142a,b,c,d), *"Cetiosaurus" brachyurus* (BMNH 2109, 2151) and *Iguanodon mantelli* (as represented by the skeleton in Brussels, IRSNB 1551) may represent a third species of *Iguanodon. I. seeleyi* may be a valid junior synonym of *I. bernissartensis* since the latter was proposed without description or diagnosis. Thus there may have been one, two or conceivably three species of *Iguanodon* during Wealden times.

The remaining four ornithopod species that have been proposed for Wealden specimens appear to represent no more than three species. *Hypsilophodon foxii* has been thoroughly analyzed by Galton (in press). *Camptosaurus valdensis*, an isolated left femur (BMNH R167), is considered a large individual of *Hypsilophodon foxii* by Galton (personal communication). *Vectisaurus valdensis*, based on a partial right ilium (BMNH R2497), a caudal centrum (BMNH R2496), three dorsal vertebrae (BMNH R2494, R2495) and two incomplete dorsal neural arches (BMNH R2498, R2499), all from the Wealden of Brixton, Isle of Wight, appears to be distinct from both *Hypsilophodon* and *Iguanodon*, but additional material is required before this can be certified. *Stenopelix valdensis* is comparable in size to the type specimen (BMNH R196) of *Hypsilophodon foxii.* However, the wax impression of the right ilium in the Humboldt Museum collections reveals a somewhat shallower posterior blade and a distinctive downward-directed distal hook on the extremity of the anterior iliac blade. Neither condition is present in the known *Hypsilophodon* specimens, but it must be emphasized here that these features were observed on a wax impression of the type specimen. According to the labels in the Humboldt Museum, the original specimen is preserved in the "Gymnasium in Bucheburg", but I was not able to locate it. The original type specimen consisted of both ilia and ischia, three or four posterior dorsals, four or five sacrals and four caudal vertebrae, plus parts of the right tibia, fibula and the right pes. Purportedly it was collected from the Hastings sand of the Wealden Beds.

In the absence of the original specimen, my observations and conclusions regarding this specimen can be only speculative. *Stenopelix* has been considered a hypsilophodontid by Nopcsa (1928a), Rozhdestvensky and Tatarinov (1964) and Romer (1966), but Huene (1956), Romer (1956) and Colbert (1961) placed it in the Psittacosauridae. The former alignment seems rather unlikely in that the ilium is very shallow from top to bottom in both the anterior and the posterior processes. In contrast, the latter process seems to have been quite deep in *Hypsilophodon.* Also, both ischia (as figured by Meyer [1859]) seem to show the strong downward curvature characteristic of ceratopsian (but not *Psittacosaurus*) ischia. Finally, the four metatarsals of the right foot appear to have been subequal in length and robusticity—features that are not typical of most ornithopods.

The evidence is aggravatingly inadequate, yet the sum total seems to favor psittacosaurian rather than hypsilophodont affinities. Relocation of the type specimen is critical for further evaluation of *Stenopelix*.

In summary, an ultraconservative roster of Wealden ornithopod species might include the following as morphologic—if not valid taxonomic—entities:

A robust *Iguanodon* (= *I. bernissartensis*?)
A slender *Iguanodon* (= *I. mantelli*?)
A Wadhurst Clay *Iguanodon* (= *I. dawsoni*?)
Hypsilophodon foxii
Vectisaurus valdensis
Stenopelix valdensis

The last species may well be of psittacosaurian, if not ceratopsian, affinity rather than ornithopod relationships.

One of the obvious similarities between the Wealden and Cloverly faunas is the dominance of ornithopods and, specifically, the abundance of moderately large ornithopods. Although there are numerous similarities in the osteology of *Iguanodon* and *Tenontosaurus*, there are also very significant differences in skull, dental, manus, pes, pelvic, pectoral and vertebral morphology. These creatures were not closely related, although at the present time they are perhaps best assigned to the same family.

The Cloverly Formation has not yet produced evidence of anything comparable to *Hypsilophodon, Stenopelix*, or *Vectisaurus*. Despite the dominance of ornithopods in both faunas, there is no evidence of very close phyletic relationship. One or more species of large *Iguanodon* during Wealden times and a solitary species of *Tenontosaurus* in the Cloverly appear to be little more than ecologic equivalents.

ANKYLOSAURIA: Perhaps most important after ornithopod remains are those of ankylosaurians in the Wealden fauna. To date, seven species have been proposed. These are listed below.

Hylaeosaurus armatus Mantell, 1833
Hylaeosaurus oweni Mantell, 1844
Regnosaurus northamptoni Mantell, 1848
Iguanodon phillipsi Seeley, 1869
Priodontognathus phillipsi Seeley, 1875
Polacanthus foxii Hulke, 1881
Polacanthus becklesi Hennig, 1925
Polacanthoides ponderosa Nopcsa, 1929

As with the preceding categories, there are taxonomic and other errors within this roster. First of all, *Hylaeosaurus oweni* is a junior synonym of *Hylaeosaurus armatus*, as they are based on the same specimen (BMNH 3775), and as far as I know the name *armatus* has not been invalidated. The type specimen of *Regnosaurus northamptoni* consists of a midlength fragment of a dentary (BMNH 2422) lacking teeth crowns. Although commonly referred to the Ankylosauria, apparently because of the near-circular sections of teeth roots, the subquadrangular cross-section of the mandible, the very large Meckelian canal, the straight tooth row and the absence of superficial dermal ossifications seem to rule out this suborder. The alveoli are subequal in size and many contain cylindrical, hollow roots. The tooth row appears to have been nearly straight and aleveoli are closely spaced (1.0 to 1.5 mm apart). The cylindrical roots, close spacing and straight tooth row could be typical of an *Astrodon* or *"Pleurocoelus"* type of sauropod. Thus sauropod, rather than ankylosaurian, affinities are possible, but the present specimen simply is not adequate for ordinal placement given our current knowledge.

A maxilla fragment (SM B53408) originally described by Seeley (1869) and named *Iguanodon phillipsi,* and later (1875) assigned by him to a new genus *Priodontognathus*, is equally difficult to place. Moreover, the specimen is from an unknown horizon, although presumed to be from the Wealden. The fragment shows no dermal sculpturing and contains no functional or fully erupted teeth in the 18 circular alveoli preserved. Several unerupted replacement teeth have been exposed and these have an acutely tapered, bladelike crown with the anterior and posterior margins strongly serrated. The denticles vary in size but there is no indication of corresponding ridges descending across the crown face. No cingula were observed. This specimen might be referred to either Stegosauria or Ankylosauria but, unfortunately, it is of little value in comparing the Wealden and Cloverly faunas.

Polacanthus foxii is based on a major portion of the posterior part of a skeleton (BMNH R175), including ilia, ischia and pubes, five sacrals co-ossified with five dorsosacrals, five incomplete dorsal vertebrae, both femora, the right fibula, several tarsals and metatarsals, 18 caudal vertebrae and numerous dermal plates and spines. Unfortunately, the specimen cannot be compared with the type specimen of *Hylaeosaurus armatus* (= *Hylaeosaurus oweni*) (BMNH 3775), which consists of the anterior part of a skeleton but no skull (right scapulocoracoid, ribs, three posterior cervicals, three dorsal vertebrae and numerous dermal spines and plates). Although they are from different localities (Barnes Chine, Isle of Wight and Cuckfield, Sussex) of undetermined stratigraphic relationships, I strongly suspect that the two specimens belong to a single species. The type material of *Polacanthoides ponderosus*, a left tibia, left humerus and left scapula (BMNH 1107, 1106 and 2584), may also belong to the same species, although there is some evidence to the contrary. The tibia compares very closely to that of *Polacanthus foxii*, but the scapula is distinct from that of *Hylaeosaurus*. The latter bears a prominent, robust, thumblike acromion process, whereas the scapula of *Polacanthoides* has a massive flangelike acromion expansion. If these three elements are from the same individual, then *Polacanthoides* would appear to be distinct from *Hylaeosaurus*.

As before, the fragmentary nature of most specimens that are the bases of Wealden ankylosaurian species permits only the most qualified comparison with *Sauropelta* from the Cloverly Formation. There are differences in the dermal armor of *Hylaeosaurus* and *Polacanthus foxii* from that of *Sauropelta*, and the scapula of *Polacanthoides* differs from that of the Cloverly species. Nevertheless, the two most complete specimens from the Wealden (*Hylaeosaurus armatus*, BMNH 3775 and *Polacanthus foxii*, BMNH R175) appear to be primitive—as is *Sauropelta*. However, without additional material, particularly cranial material, the true affinities of the Wealden ankylosaurs remain in doubt.

STEGOSAURIA: This suborder is very doubtfully represented among the fossil vertebrate collections obtained from the Wealden Beds. Seeley (1874) established a new species, *Craterosaurus pottonensis*, on a solitary dorsal neural arch that is presently housed in the Sedgewick Museum at Cambridge, England. The specimen does resemble the tall, narrow arches of *Stegosaurus*, particularly in the height of the pedicels. However, this same condition is present in many ankylosaurs (such as *Sauropelta edwardsi* and *Polacanthus foxii*), and it is quite probable that the fragmentary neural arch that is the sole basis for recognizing the Stegosauria among Wealden vertebrates (or among Cretaceous vertebrates for that matter) most probably is referable to the Ankylosauria.

CROCODILIA: Currently, four species of crocodilians are known from the Wealden, *Crocodilus cultridens* Owen, 1842 (based on a tooth), *Goniopholis crassidens* Owen, 1842 (a tooth), *Goniopholis simus* Owen, 1842 and *Bernissartia fagesi* Dollo, 1883. The type specimen of the last (IRSNB 1538, the major part of a fine skeleton) and a nearly complete specimen referred to *Goniopholis simus* (IRSNB 1537) were recovered from the *Iguanodon* level in the Bernissart coal mine and presently are displayed in the Royal Institute in Brussels.

Crocodilian teeth, the majority of which are of the narrowly tapered cone shape with fluted or grooved and ridged enamel, as in so-called *Goniopholis* teeth, are known from many other Wealden sites. These are of no systematic significance, though. Numerous indeterminate crocodilian scutes are also present.

The very fragmentary nature of most crocodilian remains from both the Wealden Beds and the Cloverly Formation, together with the very unsatisfactory state of "goniopholid" systematics, make any meaningful comparison of Cloverly and Wealden crocodilians impossible. All that can be said at this time is that both faunas include possibly similar crocodilian elements.

CHELONIA: Thirteen chelonian species have been proposed for fossil turtle remains recovered from the Wealden Beds. These are as follows:

Trionyx bakewelli Mantell, 1833
Tretosternon bakewelli Mantell, 1833
Platemys mantelli Owen, 1842
Tretosternon punctatum Owen, 1842
Chelone costata Owen, 1853
Platemys dixoni Owen, 1853
Plesiochelys bullocki Rutimeyer, 1873
Tropidemys valanginiensis Rutimeyer, 1873
Chitracephalus dumoni Dollo, 1884
Peltochelys duchasteli Dollo, 1884
Hylaeochelys koeneni Lydekker, 1889e
Desmemys bertelsmanni Wegner, 1911
Brodiechelys brodei Nopcsa, 1928b
Helochelydra Nopcsa, 1928b

Only *Peltochelys* and *Chitracephalus* are based on reasonably complete specimens. The other species are based on isolated fragments and are of doubtful affinities.

Chelonian remains from the Cloverly are even less adequate than those of the Wealden. Consequently, no significant comparisons can be made. One surprising coincidence, however, is the nearly identical pustulose ornamentation of both the carapace and plastra of *Naomichelys speciosa* from the Cloverly and *Tretosternon punctatum* and *Tretosternon bakewelli* from the Wealden. It is unlikely that this is more than coincidence but with the existing fragments no other interpretation is possible.

VERTEBRATE FAUNAS OF THE WEALDEN AND CLOVERLY FORMATIONS
(From Casier, 1960; Clemens, 1963; C. Patterson, 1966; and others)

WEALDEN		CLOVERLY
	Class Chondrichthyes	
	Order Selachii	
	Suborder Hybodontoidea	
	Family Hybodontidae	
Hybodus basanus		
Hybodus ensis		
Hybodus parvidens		
Hybodus brevicostatus		
Lonchidion breve		
Lonchidion striatum		
Lonchidion rhizion		
Lonchidion heterodon		
	Family Ptychodontidae	
Hylaeobatis ornata		
	Class Osteichthyes	
	Order Palaeonisciformes	
	Suborder Palaeoniscoidei	
	Family Coccolepidae	
Coccolepis macropterus		
	Order Semionotiformes	
	Suborder Semionotoidei	
	Family Semionotidae	
Lepidotus mantelli		
Lepidotus bernissartensis		
Lepidotus brevifulcratus		
Lepidotus arcuatus		
	Order Pycnodontiformes	
	Family Pycnodontidae	
Coelodus mantelli		
Mesodon bernissartensis		
	Order Amiiformes	
	Suborder Amioidei	
		Cloverly amioid
	Family Caturidae	
Callopterus insignis		
Caturus tenuidens		

	Family Amiidae	
Amiopsis dolloi		
Amiopsis lata		
	Family Macrosemiidae	
Notagogus parvus		
	Order Pholidophoriformes	
	Family Pholidophoridae	
Pholidophorus obesus		
	Family Pleuropholidae	
Pleuropholus sp.		
	Order Leptolepiformes	
	Family Leptolepidae	
Clupavus sp.		
	Order Clupeiformes	
	Suborder Clupeoidei	
	Family Chirocentridae	
Pachythrissops sp.		
	Order Dipnoi	
	Family Ceratodontidae	
		Ceratodus frazieri
	Class Amphibia	
	Order Urodela	
	Family Proteidae	
Hylaeobatrachus croyi		
	Class Reptilia	
	Order Testudinata	
	Suborder Amphichelydia	
	Family Pleurosternidae	
Desmemys bertelsmanni		
Plesiochelys bullocki		
	Family Plesiochelyidae	
Brodiechelys brodei		
Hyaelochelys koeneni		
	Family Thalassemyidae	
Tropidemys valanginiensis		
	Family Apartotemporalidae	
Chitracephalus dumoni		
	Suborder Cryptodira	
	Family Glyptopsidae	
		Naomichelys speciosa
		Glyptops pervicax
	Family Dermatemydidae	
Tretosternon punctatum		
Tretosternon bakewelli		
Peltochelys duchasteli		
	Family Chelydridae	
Helochelydra sp.		

	Family Testudinidae	
Platemys mantelli		Cloverly testudinid?
Platemys dixoni		
	Family Cheloniidae	
Chelone costatus		
	Order Crocodilia	
	Suborder Mesosuchia	
	Family Goniopholidae	
Goniopholis simus		Cloverly crocodilian
	Suborder Eusuchia	
	Family Hylaeochampsidae	
Bernissartia fagesi		
	Order Saurischia	
	Suborder Sauropodomorpha	
	Family Brachiosauridae	
Cetiosaurus conybeari		
	Family Titanosauridae	
Pelorosaurus becklesii		Cloverly titanosaurid
	Family *incertae sedis*	
Ornithopsis hulkei		
Bothriospondylus elongatus		
Bothriospondylus magnus		
Chondrosteosaurus gigas		
Ornithopsis eucamerotus		
Pleurocoelus valdensis		
Titanosaurus valdensis		
	Suborder Theropoda	
	Family Coeluridae	
Aristosuchus pussillus		*Microvenator celer*
Thecospondylus horneri		
Thecocoelurus daviesi		
Calamosaurus foxii		
	Family Dromaeosauridae	
		Deinonychus antirrhopus
	Family Megalosauridae	
Megalosaurus oweni		Cloverly carnosaur
Megalosaurus dunkeri		
	Family Ornithomimidae	
		Cloverly ornithomimid
	Order Ornithischia	
	Suborder Ornithopoda	
	Family Hypsilophodontidae	
Hypsilophodon foxii		
	Family Iguanodontidae	
Iguanodon bernissartensis		*Tenontosaurus tilletti*
Iguanodon mantelli		
Iguanodon dawsoni		
Vectisaurus valdensis		
	Family Psittacosauridae?	
Stenopelix valdensis		

	Suborder Ankylosauria Family Acanthopholidae	
Hylaeosaurus armatus *Regnosaurus northamptoni* *Priodontognathus phillipsi* *Polacanthus foxii* *Polacanthoides ponderosus*		*Sauropelta edwardsi*
	Suborder Stegosauria? Family Stegosauridae?	
Craterosaurus pottonensis		
	Class Mammalia Order Multituberculata Family Plagiaulacidae	
Loxaulax valdensis		
	Order Pantotheria Family Dryolestidae	
Melanodon goodrichi		
	Order Symmetrodonta Family Spalacotheriidae	
Spalacotherium tricuspidens		

DISCUSSION

One major difficulty in comparing the Wealden and Cloverly faunas is the great discrepancy in the numbers of taxa that have been described from each. Sixty or more species (excluding fish) have been proposed for the vertebrate remains from the Wealden Beds, whereas only six are listed here from the Cloverly Formation. (Evidence of perhaps seven or eight additional Cloverly species was deemed inadequate for founding formal binomials.) This discrepancy is easily explained: more than a century of collecting from the Wealden Beds compared with slightly less than 40 years for the Cloverly, and the early tendency (obsolete but not entirely abandoned even now) to propose formal binomials for even the most fragmentary remains.

When the Wealden list is considered carefully, with the object of eliminating all possible synonyms, a greatly shortened faunal list results. The sauropod remains, for example, include only one basic type of tooth, but there are two distinctly different humeri (*Pelorosaurus conybeari*, BMNH 28626 and *Pelorosaurus becklesii*, BMNH R1868). Similarly there appear to be two types of dorsal vertebrae (*Ornithopsis hulkei*, BMNH 28632 and *Bothriospondylus elongatus*, BMNH 2239). All other sauropod remains could conceivably belong to one of these two kinds. Thus there may have been as few as two species of sauropods in the Wealden. There is evidence for only one certain species in the Cloverly. The sauropod postcranial remains of these two formations are not comparable, but the dental evidence is and indicates that the Wealden and Cloverly sauropods may have been closely related.

The absolute minimum number of theropod species represented in the Wealden evidence could be two—one small species (*Calamospondylus oweni*?) and one large species (*Megalosaurus dunkeri*?) The Cloverly contains a minimum of four species: one large species (undefinable), one ornithomimid, one small species (*Deinonychus* *antirrhopus*), and one very small species (*Microvenator celer*). The relationships between New and Old World theropods cannot be established.

The number of Wealden ornithopod species could be as low as four: *Iguanodon anglicum, Vectisaurus valdensis, Hypsilophodon foxii* and *Stenopelix valdensis*. From the Cloverly, there is evidence of only one ornithopod species, *Tenontosaurus tilletti*, unless some of the fragmentary remains of small individuals have been incorrectly interpreted as juveniles. *Tenontosaurus* does not appear to be especially close to any of the Wealden forms unless it be *Vectisaurus* (which conceivably could be either an immature *Iguanodon* or a more *Camptosaurus*-like form). All that can be said here is that both faunas included a moderate- or large-sized ornithopod, which appears to be dominant in both.

The Wealden ankylosaur fauna is reducible to a minimum of two species on the basis of the distinctly different scapulo-coracoids of *Hylaeosaurus armatus* and *Polacanthoides ponderosus*. Evidence of only one ankylosaurian species, *Sauropelta edwardsi*, is known from the Cloverly. All ankylosaurian remains from both units appear to be primitive and are perhaps best referred to the Acanthopholidae.

The overall similarity in the general compositions of the Wealden, Cloverly and Arundel faunas strongly suggests similar ages. These faunal similarities also reflect similar ecologic factors, but the latter appear to be of secondary importance. No precise tally of numbers of individuals can be given, but even it if could, without precise stratigraphic data it would have little meaning. However, having examined nearly all of the specimens collected from these three formations, I have clear impressions of the relative abundances of the tetrapod elements of the three faunas. Qualitative though they are, the following summary suggests distinctive ecologies for all three:

	CLOVERLY	ARUNDEL	WEALDEN
	Ornithopoda	Sauropoda	Ornithopoda
Decreasing Abundance ↓	Ankylosauria	Theropoda	Sauropoda
	Sauropoda	Ankylosauria	Ankylosauria
	Theropoda	Crocodilia	Theropoda
	Crocodilia	Chelonia	Chelonia
	Chelonia		Crocodilia

In all three faunas, I estimate the most common group to be approximately five times more abundant than the second most common group. In the Cloverly fauna, ornithopods outnumber all other elements combined and I suspect the same would be true of the Wealden fauna. The total absence of ornithopods in the Arundel fauna, although negative evidence, takes on added significance in this light.

6. AGE OF THE CLOVERLY FORMATION

The discontinuous fossil record of terrestrial vertebrates and the rarity of Early Cretaceous vertebrate remains in particular preclude precise dating of the Cloverly Formation on the basis of its vertebrate fauna alone. Other evidence must be considered. Peck and Craig (1962) reported that the "Lower Cretaceous" nonmarine sediments of Wyoming and adjacent states (Kootenai, Cloverly, Burro Canyon, Peterson, and Lakota Formations) contain ostracods and charophytes (Cyprideinae and Clavatoraceae) that elsewhere (western interior, Gulf Coast region, Europe, Asia and Africa) are of Aptian age. Unfortunately, no samples were available to them from the Cloverly Formation within the Bighorn Basin. Cloverly samples that were analyzed by them were collected from the Wind River Basin, the northwest flank of the Wind River Mountains, the Jackson Hole area, the Rawlins uplift and the north flank of the Uinta Mountains. Kootenai samples were obtained from southwest and western Montana (Beaverhead and Powell Counties). Thus their samples that are most relevant to this study were collected well outside of our study area. Consequently, until similar analyses are made of the microfauna of the Cloverly Formation within the Bighorn Basin area, we must consider Aptian as only a probable maximum age for these strata. Whether the entire Cloverly sequence, from Unit IV to Unit VII, is of Aptian age is not known. It is of particular interest, however, that Peck and Craig note that collections from the Cloverly "are mostly from calcareous clays associated with the limestones of the middle variegated clay unit". This description seems to correspond to our Unit V, rather than VII, so it is conceivable that the upper part of the Cloverly Formation is Lower Albian. The occurrence within our study area of *Inoceramus comancheanus* and *Haplophragmoides gigas* (Eicher, 1962) in the upper 25 feet (7.6 m) of the Thermopolis Shale (as that unit was redefined by Eicher in 1960) establishes a minimum age limit of Middle Albian for the underlying Sykes Mountain and Cloverly Formations.

As I noted above, two undescribed specimens from the Glen Rose Formation of the Trinity Group of northern Texas appear to be conspecific with specimens from the Cloverly Formation. One is a skull (OU 8-0-S2) that seems referable to *Tenontosaurus tilletti*. The other is a complete turtle skeleton (FMNH PR-273) referable to *Naomichelys speciosa*. Unfortunately, precise stratigraphic data are not available for these specimens, but both are recorded as from the Glen Rose Formation. Stanton (1947), on the basis of numerous collections of pelecypods and gastropods from the Trinity Group, has judged the Glen Rose Formation to be basal Middle Albian in age. Thus the Glen Rose appears to be slightly older than the Thermopolis Shale and younger than the ostracod-charophyte faunas of middle or lower(?) Cloverly. Both of the above specimens require careful study to ascertain whether in fact they are conspecific with Cloverly specimens.

Stanton's age for the Glen Rose corresponds with the Trinity placement given by Stephenson et al. (1942) and is consistent with Wieland's (1931) belief that the Trinity cycadeoids compare most closely with those of the lower Lakota. Thus, with all due respect for our present lack of precise stratigraphic control of paleontologic sites in both formations, it is probable that parts of the Glen Rose and Cloverly Formations are temporal equivalents. The latter most probably is late Aptian (Unit V?) to Early Albian (Unit VII?).

Our present state of knowledge about Mesozoic tetrapod ecology and phyletic relationships makes it difficult to explain the differences between the Morrison and Cloverly faunas. Moberly (1960) has presented important lithologic evidence indicating a significant change in the physical environment from Morrison to Cloverly time. Thus, the Morrison to Cloverly faunal change could well be an ecologic, rather than a simple evolutionary transition. The fact that few, if any, of the Cloverly taxa are clearly derivable from Morrison species, together with the fact that the Cloverly fauna is more closely allied with Late Cretaceous vertebrates than with those of the Morrison (or Jurassic) (in Brown's opinion [1941a] and mine) indicates either immigration of a new fauna or a major temporal hiatus between the Morrison and Cloverly faunas. If the Kimmeridgian age generally assigned to the Morrison fauna is correct, a hiatus equal to most or all of Portlandian and Neocomian time exists—an interval of perhaps 18 to 20 million years.

Marsh (1888) correlated the Arundel fauna with that of the *Atlantosaurus* beds (Morrison Formation), as did Lull (1911a). This interpretation was based largely on the presence of sauropod remains, which at that time were not known to occur above the Jurassic in North America. Hatcher (1903) provided additional, but doubtful, evidence for the correlation when he referred two pleurocoelous centra from the "*Atlantosaurus* beds" on Sheep Creek, Albany County, Wyoming to *Astrodon* (*Pleurocoelus*). Ample evidence now exists showing that sauropods survived to Late Cretaceous times, and Hatcher's vertebrae are suspect and not positively referable to any genus. Berry (1911), on the basis of the flora contained in the Patuxent Formation (immediately beneath the Arundel Formation), concluded that these Maryland strata were of Early Cretaceous age and equated the Patuxent with the Kootenai Formation of Montana. In the same paper, he concluded that the Patuxent-Arundel flora and fauna span all but the earliest part (Berriasian) of the Neocomian. Stephenson et al. (1942) accepted this placement.

Allen (1955) and Hughes (1958) have concluded that the Wealden Beds range from Berriasian at the base (Fairlight Clay) to Barremian or Lower Aptian at the top (Upper Wealden Clay), encompassing the entire Neocomian of North American terminology. This conclusion is based primarily on plant microspores and megaspores. Clemens (1963) found no evidence in the mammalian remains to challenge this post-Tithonian pre-Aptian age for the Wealden Beds. The mammal remains are from the Ashdown Beds (lower Wealden) and the Grinstead Clay (mid-Wealden). Thus, the Wealden vertebrate fauna, which is chiefly from the Wadhurst Clay immediately overlying the Ashdown Beds and from the Wealden Clay, appears to be distinctly older than the Cloverly fauna.

The probable ages of the Cloverly, Trinity, Arundel and Wealden strata are summarized below.

		European Stages	Wyoming and Montana	Texas and Oklahoma	Maryland	Northwestern Europe
Lower Cretaceous		Albian				
			Cloverly Formation	Glen Rose Formation (Trinity)		
		Aptian				
	Neocomian	Barremian			Arundel	Wealden Beds
		Hauterivian				
		Valanginian			Patuxent	
		Berriasian				

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APPENDIX A

MEASURED SECTIONS

Multiplicity of definitions and inconsistent use of the terms "Cloverly" and "Morrison" by both past and current workers make it necessary to provide careful comparisons of these applications and those used in this report. The section on stratigraphy discusses this matter at length, based on extensive field observations, and is supplemented by Charts I through VII. In addition, the following 28 measured sections (Fig. 4) are presented.

Each of the following measured sections is preceded by a brief statement giving the location and other pertinent comments. Wherever possible, parts of a section are equated with formal units proposed by other workers. Many, but not all, of these sections were measured at or in the vicinity of fossil vertebrate sites, the levels of these sites are indicated. I measured all sections, most with a Brunton compass, others with a steel tape. All sections were measured at sites where the strata were dipping gently or flat-lying. In all sections Unit VIII was used as the uppermost datum and only the lower massive sandstone was measured.

SECTION 1 - CODY, WYOMING

Measured in the southwest-facing exposures 1.3 miles (2 km) south of Cody on the east limb of Horse Center Anticline. NE 1/4, Sec. 11, T. 52 N., R. 102 W., Park County, Wyoming.

	Thickness (ft)	Thickness (m)
SYKES MOUNTAIN FORMATION:		
11. Massive and thin-bedded quartz sandstone, interbedded with occasional, thin beds of dark-gray, fissile shale. Sandstone, medium- to fine-grained, tan to buff on fresh surfaces, weathers to rusty brown. Ironstone nodules and hematite staining abundant, ripple marks and fucoid impressions common. Overlain by black fissile shale of Thermopolis Formation (= Greybull sandstone?; Sykes Mountain Formation in part; Unit VIII of this report)........	>32	>9.7

	Thickness (ft)	(m)
CLOVERLY FORMATION:		
10. Variegated claystone, reddish-brown to purple in lower 60 feet (18.3 m), grading to rusty red near top. Silty throughout. Occasional discontinuous 6 to 10 inch (15 to 25 cm) sandstone lenses. Claystone, non-stratified, mottled gray-green and purple on fresh surfaces. Some polished pebbles or so-called "gastroliths", and satin spar. Chalcedony, barite and calcareous concretions absent. (=Himes Member of Cloverly Formation in part?; Unit VII of this report)........................	82	25
9. Sandstone, fine- to medium-grained, massive, parallel stratification. Iron-oxide pellets throughout, quartz and some feldspar. Buff to tan on fresh surfaces, weathers tan to light brown. (=Darton's basal sandstone?; Unit VI of this report)	8	2.4
8. Claystone, variegated, purple to dark-gray in upper half, pastel to light-gray below. Massive, to poorly stratified. Weathers to "popcorn" surface; bentonitic, abundant chalcedony concretions, white to orange satin spar, some selenite crystals. Occasional, discontinuous 6 to 15 inch (15 to 38 cm) sandy zones and strata. Polished pebbles lacking. (=Little Sheep Mudstone Member, Cloverly Formation?; Unit V of this report)...................	180	54.9
7. Sandstone, quartz, coarse-grained, massive, yellow on fresh surface, weathers to yellow brown. Forms prominent ledge here, but is less conspicuous at exposures 1 to 2 miles (1.6 to 3.2 km) to south......................................	3	0.9
6. Claystone, variegated, gray to pinkish-gray, unstratified, gray on fresh surfaces. Some chalcedony concretions and at least one sandy zone.....	49	14.9
MORRISON FORMATION:		
5. Sandstone, white to buff, medium- to coarse-grained, quartz, clay pellets and occasional 0.25 to 0.50 inch (0.6 to 1.2 cm) pebbles. Massive and strongly cross-laminated, some strata 8 to 12 feet (2.4 to 4.1 m) thick. Some levels friable, but generally well indurated. Iron staining and		

	Thickness (ft)	Thickness (m)
frequent ironstone concretions in upper 3 to 6 feet (0.9 to 1.8 m). (Equated by Lee, 1927, with "lower" Cloverly sandstone"; designated Unit II here.)	86	26.2
4. Claystone, calcareous, variegated-pink, reddish-brown, gray-green and light-gray with occasional thin, tan, medium-grained sandstone strata. Chalcedony, and gypsum conspicuous by their absence. Claystone poorly to unstratified and silty throughout. (= Morrison Formation; part of Unit I of this report)	107	32.6
3. Sandstone, massive and thin-bedded, interbedded with massive claystone and thin-bedded fissile shale. Sandstone fine-grained, quartz, white to very light-gray. Shale and claystone light-gray to gray-green. Entire sequence variable laterally.	37	11.3
2. Concealed. Apparently nonresistant claystone.	25- 40	7.6- 12.2

SUNDANCE FORMATION:

	Thickness (ft)	Thickness (m)
1. Sandstones and shales, interbedded, glauconitic, containing abundant marine invertebrates, *Gryphaea*, and belemnites. (= Upper Sundance Formation)	Not measured	

Concealed

SECTION 2 - MARQUETTE CREEK

Measured in the prominent, north-facing exposures, 1.5 miles (2.4 km) south of the Hill ranch, 0.5 mile (0.8 km) east of Marquette Creek. SE 1/4, Sec. 21 and SW 1/4, Sec. 22, T. 51 N., R. 103 W., Park County, Wyoming.

SYKES MOUNTAIN FORMATION:

	Thickness (ft)	Thickness (m)
8. Sandstone, thinly laminated to massive, interbedded with thin layers of fissile black shale. Sandstone fine- to medium-grained, tan fresh, weathering to brown. Ripple marks common. Ironstone concretions present in overlying shale and sands. (= Greybull sandstone?; Sykes Mountain Formation in part; Unit VIII of this report)	> 6	>1.8

	Thickness (ft)	(m)
CLOVERLY FORMATION:		
7. Claystone, variegated, maroon to red-brown, becoming rusty toward top. Fresh surfaces purple-gray with green mottling. Generally sandy. Massive to poorly stratified. Polished pebbles or "gastroliths" frequent. (= Himes Member, Cloverly Formation in part; Unit VII of this report)........	48	14.6
6. Sandstone, olive-yellow, weathering yellow brown, massive, variably indurated, some cross-lamination, medium-grained, quartz, feldspar and white chert. (= Darton's basal sandstone?; Unit VI of this report)..................................	1.5- 3	0.5- 0.9
5. Claystone, variegated, gray to purplish, dark- to light-gray on fresh surface. Unstratified, breaks into irregular, "greasy"-surfaced chips, bentonitic, weathering to "popcorn"-covered slopes. Chalcedony concretions and pink to orange satin spar common. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)................	86	26.2
4. Chalcedony zone, irregular concretionary masses of purple, blue, white and yellow chalcedony and barite in light-gray claystone. Forms prominent ledge or caps small knolls. (= Unit V in part of this report).................................	2- 4	0.6- 1.2
MORRISON FORMATION:		
3. Claystone, variegated dark to light-gray, purplish zones locally and conspicuous orange to rust-yellow zone near top. Fresh surfaces dark- to light-gray, nonfissile and unstratified. Highly bentonitic. (= Unit III? of this report)...............	84	25.6
2. Concealed................................	48- 60	14.6- 18.3
1. Sandstone, massive, cross-laminated, medium- to coarse-grained, quartz and white chert, with few pebbles. White to buff, weathers white to yellowish. Base concealed. (= Unit II? of this report)....	42	12.8

Concealed.

SECTION 3 - SOUTH FORK COAL DRAW

Measured in the east-facing exposures at the west end of Thermopolis Anticline, 1.5 miles (2.4 km) west of South Fork of Coal Draw, 11 miles (17.6 km) northwest of Thermopolis, Wyoming. SW 1/4 Sec. 27 and SE 1/4 Sec. 28, T. 44 N., R. 96 W., Hot Springs County, Wyoming.

SYKES MOUNTAIN FORMATION:	Thickness (ft)	(m)
13. Sandstone, tan to light-brown, with hematite staining and ironstone concretions near top. Massive to thin-bedded, abundant ripple marks, and fucoids. Fine- to medium-grained, chiefly quartz grains. Overlain by fissile black shales and thin sandstone strata. (= Greybull sandstone?; Sykes Mountain Formation in part; Unit VIII of this report)........	12.5	3.8
CLOVERLY FORMATION:		
12. Claystone, variegated, weathers maroon, purple, rose and gray; gray to pink or purple-gray with green mottling on fresh surfaces. Massive to poorly stratified. Silty throughout, some polished pebbles. (= part of Himes Member, Cloverly Formation; Unit VII of this report)............................	22	6.7
11. Limestone, massive, light-gray weathers white, finely crystalline............................	1-3	0.3-0.9
10. Claystone, variegated, weathering to maroon and red brown, unstratified, forming steep, fluted slopes. Polished stones or "gastroliths" present, but not abundant. Locality YPM 66-2 is located near the middle of this claystone. (= part of Himes Member, Cloverly Formation; Unit VII of this report)................................	37	11.3
9. Claystone, variegated, weathers red to red brown in lower half and purple, rose and nearly white in upper part; generally medium-gray to yellow-gray on fresh surfaces. Thin (6 to 10 inch [15 to 25 cm]), discontinuous, brown and white limestone strata present locally. Chalcedony, barite and calcerous concretions abundant throughout. Bentonitic, weathers to "popcorn" surfaces. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)....................................	22	6.7

	Thickness	
	(ft)	(m)
8. Sandstone, massive, weathers brown; pale-green to light-gray on fresh surfaces, fine- to medium-grained, quartz, white chert and some black chert grains. Occasional coarse grains but not conglomeratic, parallel stratification and occasional cross-lamination. (= Unit IV? of this report)	12.5	3.8
MORRISON FORMATION:		
7. Claystone, medium- to light-gray, with numerous thin tan sandstone strata, and thin white limestone layers. Conspicuous limestone concretion zone at base. Claystone grades into fissile dark shale interbeds at top. (= part of Unit III of this report).	18	5.5
6. Claystone, green to yellow-gray, massive or unstratified. Fresh surfaces gray. Calcareous, discontinuous sandy zone near base. (= part of Unit III of this report)	64.5	19.6
5. Sandstone, weathers yellow brown, soft, friable, poorly cemented. Quartz grains, medium-grained.	2	0.6
4. Claystone, sandy, greenish-yellow, massive, unstratified; forms partly concealed slopes.	13	3.9
3. Sandstone, massive, weathers tan or white; white and sparkly on fresh surface. Weathers into rounded knobs and blocks. Quartz and white chert, medium-grained. Not conglomeratic. Individual beds up to 10 and 15 feet (3 and 4.5 m) thick. (= Unit II of this report)	48	14.6
2. Concealed.	>10	> 3
SUNDANCE FORMATION:		
1. Sandstone and shale, interbedded, glauconitic. Occasional mollusc shells and belemnites	Not measured	

Concealed.

SECTION 4 - MUD CREEK

Section measured in west-facing exposures 1.5 miles (2.4 km) southeast of Mud Creek, just west of the head of Rattlesnake Gulch, 7 miles (11.2 km) due west of Thermopolis. NE 1/4 Sec. 35, T.43 N., R.96W., Hot Springs County, Wyoming.

		Thickness (ft)	Thickness (m)
SYKES MOUNTAIN FORMATION:			
12.	Sandstone, yellow to tan, medium- to fine-grained, weathering "rusty" to brown, thin-bedded and massive with ripple marks and fucoidal markings. Overlain by dark-gray to black fissile shale and ironstone lamina interbedded with thin, brown sandstone strata. (= Greybull sandstone?; Sykes Mountain Formation in part; Unit VIII of this report).........	>10	> 3
11.	Claystone and shale, medium-gray to black, massive below, becoming thin-bedded and fissile near the top. Silty throughout. Weathers to "rusty" color. (= Himes Member, Cloverly Formation in part?; part of Unit VIII of this report)	18	5.5
CLOVERLY FORMATION:			
10.	Claystone, variegated, pink, lavender, and maroon with gray or green mottling on fresh surfaces. Upper 35 feet (10.6 m) generally more pastel. Massive, unstratified, silty throughout. Polished pebbles common. (= part of Himes Member, Cloverly Formation; Unit VII of this report)................	65±	19.8±
9.	Claystone, variegated, gray to purple, bentonitic. Massive, breaks into dark-gray irregular chips. Chalcedony concretions abundant. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)..................................	32±	9.7±
8.	Sandstone, fine-grained quartz, blocky and well-indurated. Light-gray on fresh surfaces, weathers gray. Ripple marks prominent	1-2	0.3-0.6
MORRISON FORMATION:			
7.	Claystone, variegated purple to red-brown, green mottling prominent on fresh surfaces. Unstratified. Calcareous. Infrequent satin spar, but apparently lacking in chalcedony, barite and limestone concretions. (= Unit III? of this report)	26.5	8.1

		Thickness	
		(ft)	(m)
6.	Siltstone, siliceous, white, sparkly, weathers gray. Very well indurated.	1	0.3
5.	Claystone, lime-green to light-gray, silty at base, weathers yellow to buff. Unstratified. (= part of Unit III of this report).	7.5	2.3
4.	Siltstone, white to gray, thin-bedded with occasional 1 inch (2.5 cm) stratum of sandstone. Weathers buff. (= part of Unit II of this report).	13	3.9
3.	Sandstone, coarse to fine-grained with an occasional pebbly zone, massive, strongly cross-laminated, white to buff, weathers gray with some yellow staining. Grains well-rounded, quartz, some feldspar and white chert. Forms prominent ledges. (= part of Unit II of this report).	32	9.7
2.	Concealed — unknown thickness.	-	-
1.	Claystone, gray to greenish, weathers a yellow tan. Largely covered. Sandy. Some discontinuous sand strata 3 to 6 inches (7.5 to 15 cm) thick. Thickness unknown.	-	-

Concealed.

SECTION 5 - THERMOPOLIS (I), WYOMING

This section was measured on the west side of U.S. 20, 3 miles (4.8 km) north of Thermopolis in the exposures of the road cut and along the ridge to the west on the north limb of the Thermopolis Anticline. N 1/2, Sec. 24, T. 43 N., R. 94 W., Hot Springs County, Wyoming.

SYKES MOUNTAIN FORMATION:

10. Sandstone, tan to brown on weathered surfaces, buff to light-gray on fresh surfaces, massive, becoming thin-bedded toward top. Ripple marked. Fine- to medium-grained, chiefly quartz. Hematite staining and ironstone concretions in upper levels. Overlain by interbedded black fissile

		Thickness	
		(ft)	(m)
	shale and thin brown sandstone beds. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)	9	2.7

CLOVERLY FORMATION:

9.	Claystone, variegated, light-gray to pink-gray on fresh surfaces with small patches of red-brown mottling, weathers to pale maroon. Unstratified. One foot (0.3 m) thick pink-gray siltstone near middle of unit. (= part of Himes Member, Cloverly Formation; part of Unit VII of this report).	17	5.2
8.	Sandstone, massive, medium-grained rounded quartz. Conspicuous parallel stratification. Weathers light brown, tan on fresh surface	5	1.5
7.	Claystone, variegated, lavender, maroon to red-brown with green mottling on fresh surfaces, tan to gray near top. Silty in lower 8 to 10 feet (2.4 to 3.0 m). Sandy zone about 15 feet (4.5m) below top. Massive throughout. Polished pebbles or "gastroliths" moderately abundant. (= Himes Member, Cloverly Formation; Unit VII of this report)	45.5	13.9
6.	Sandstone, conglomeratic in lower half. White to tan, massive, medium- to coarse-grained quartz, quartzite and white chert. Conglomeratic wedges increasingly abundant toward base with pebbles of quartzite and white chert up to 0.5 inch (1.2 cm) in diameter. Some feldspar. (= Darton's lower sandstone, Cloverly Formation; Otter Creek Sandstone?; Unit VI of this report)	35	10.6
5.	Conglomeratic sandstone, massive, dark-gray or brown. Appears to grade abruptly into overlying unit. Pebbles chiefly of black and brown chert, some quartz, up to 0.5 and 1 inch (1.2 and 2.5 cm) in diameter. (= Pryor Conglomerate ?; Unit IV? of this report)	15	4.5

	Thickness (ft)	(m)
MORRISON FORMATION:		
4. Claystone, sandy, greenish-tan and gray. Nonresistant and partly covered. Occasional indurated sand strata 1 to 2 feet (0.3 to 0.6 m) thick, all apparently discontinuous. Claystone unstratified. (= Unit III of this report)	91	27.7
3. Sandstone, brilliant white to yellow, quartz and white chert in medium-sized grains. Chalky-white grains of chert conspicuous. Entire unit is massive, with cross-laminations throughout. Generally somewhat friable, weathering into smooth, rounded, sloping surfaces and isolated pedestals and knobs. No conglomeratic zones noted. (= Unit II of this report)	134	40.8
2. Concealed, thickness undetermined but in excess of 10 feet (3.0 m)	> 10	> 3
SUNDANCE FORMATION:		
1. Sandstone, glauconitic, weathering from pale green to light brown. Marine invertebrate remains common 20 feet (6.0 m) below top	Not measured	
Concealed		

SECTION 6 - THERMOPOLIS (II), WYOMING

This section was measured on the east side of the Bighorn River directly across from Section 5, on the north limb of the Thermopolis Anticline. SE 1/4, Sec. 19, T.43 N., R.94 W., Hot Springs County, Wyoming. The section is included here because it contains a sequence significantly different from that described in Section 5 slightly over a mile (1.6 km) away, a sequence that I believe provides the best evidence for correlation of sections on all sides of the Bighorn Basin.

SYKES MOUNTAIN FORMATION:

9. Sandstone, buff to gray on fresh surfaces, weathering tan to rusty brown. Massive and thin bedded, fine- to medium-grained, predominantly quartz in well-rounded grains. Ripple marks and fucoids common at various levels.

	Thickness (ft)	Thickness (m)
Some hematite lamina and staining near top and in overlying black shales and thin sandstone. (= Greybull sandstone; Sykes Mountain Formation in part: Unit VIII of this report)	8	2.4
CLOVERLY FORMATION:		
8. Claystone, variegated, maroon, red-brown, lavender to gray, green mottling on fresh surfaces. Sandy in upper half and near base. Massive or unstratified. Polished pebbles infrequent. (= Himes Member, Cloverly Formation; Unit VII of this report)	52	15.8
7. Sandstone, white to light-gray or tan, massive with cross-laminations. Medium- to coarse-grained, conglomeratic in lower half. Chiefly quartz, white quartzite and white chert and some feldspar. Almost no dark grains or pebbles. Well-cemented, forms large blocks on lower slopes. (= Otter Creek Sandstone ?; Unit VI of this report)..................	58	17.7
6. Shales, dark-gray to gray-green and brown, thin seams of coal and lignite shales, highly fissile. (= part of Unit V? of this report)	12	3.6
5. Conglomerate, massive, dark-brown, both on fresh and weathered surfaces. Cross-laminations common. Consists of moderately well-rounded grains and pebbles up to 0.5 and 1 inch (1.2 and 2.5 cm) in diameter, of dark-gray to black chert, dark quartzite, yellow-brown and white quartzite. Less than 10% of material is light-colored. Overall appearance and composition very similar to those of the Pryor Conglomerate. (= Pryor Conglomerate ?; Unit IV of this report)	28	8.5
MORRISON FORMATION:		
4. Claystone, greenish to light-gray, silty throughout with occasional thin sandstone strata. Claystone poorly stratified. Concretions lacking. Fresh rock dark gray-green, breaking into irregular chips. Calcareous. (= Unit III of this report)....	90	27.4

Thickness
(ft) (m)

3. Sandstone, brilliant white to pale-yellow or buff. Medium-grained quartz and white chert. Chalky-white grains of chert a prominent feature giving a white "spattered" appearance to fresh surfaces. Dark grains extremely rare. Weathers into smooth massive, rounded surfaces and isolated knobs. (= Unit II of this report)...................... 45 13.7

2. Concealed interval, apparently of nonresistant lithology. Equals at least 10 feet (3 m)......... >10 >3

SUNDANCE FORMATION:

1. Sandstone thin-bedded and glauconitic. Marine invertebrate shells common in sands and shales beneath................................... Not measured

Concealed

SECTION 7 - NOWOOD CREEK

Section measured at limited exposures near ridge top 1 mile (1.6 km) west of Nowood Creek and "Orchard Ranch", Sec. 4 (?), T.42 N., R.88 W., Washakie County, Wyoming.

SYKES MOUNTAIN FORMATION:

3. Sandstone, light-gray, weathering tan to yellow, fine- to medium-grained, sparkly, massive strata cross-laminated, ironstone nodules abundant in upper part, overlain by thinly laminate fissile black shale. (= Greybull sandstone: Sykes Mountain Formation in part; Unit VIII of this report)........ 15 4.5

CLOVERLY FORMATION:

2. Claystone, variegated red-brown to maroon-gray, unstratified, sandy. Polished pebbles or "gastroliths" infrequent. (= Himes Member, Cloverly Formation; Unit VII of this report) 33 10

1. Sandstone, white to yellow, fine- to coarse-grained, conglomeratic in places, quartz, white chert. Friable, cross-laminated, exposures prominent. (= lower sandstone, Cloverly Formation; Otter Creek Sandstone; Unit VI of this report).................. 76 23.2

Concealed.

SECTION 8 - BIG TRAILS, WYOMING

Section 8 was measured across the west limb of Bud Kimball Anticline, 0.5 mile (0.8 km) north of Nowood Creek, approximately 4.5 miles (7.2 km) northwest of Big Trails, Wyoming. SW 1/4 Sec. 30, T. 45 N., R. 87 W. and SE 1/4 Sec. 25, T. 45 N., R. 88 W., Washakie County, Wyoming.

		Thickness	
SYKES MOUNTAIN FORMATION:		(ft)	(m)
12.	Sandstone, tan to rust-brown, thin-bedded, fine-grained, quartz dominant. Ripple marks and fucoids common on nearly all exposed bedding planes. Hematite staining prevalent. Overlain by dark-gray fissile shale and thin dark-brown sandstone lamina. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)	5	1.5
CLOVERLY FORMATION:			
11.	Claystone, massive, variegated, purple to gray-white, yellow near top. Sandy or silty throughout. "Gastroliths" or polished pebbles common, chalcedony and barite concretions lacking. (= Himes Member, Cloverly Formation?; middle shale member of Darton's Cloverly Formation; Unit VII of this report)	35	10.6
10.	Sandstone, massive, yellow to tan, fresh surfaces yellow, medium- to coarse-grained, chiefly quartz, some feldspar and white chert. Not conglomeratic. Friable in places, but generally well-cemented. (= lower sandstone member of Darton's Cloverly Formation?; Otter Creek Sandstone; Unit VI of this report)	55	16.7
MORRISON FORMATION:			
9.	Claystone, variegated, greenish-yellow, tan, very light-gray. Massive or unstratified, calcareous and sandy. Some satin spar, but chalcedony and barite concretions absent. (= Unit III? of this report)	75	22.8
8.	Sandstone, massive, white to buff, medium-grained, quartz and white chert in well-rounded grains. Dark minerals, negligible. Chalky white spots of chert grains characteristic. Weathers into smooth, rounded surfaces. (= Unit II? of this report)	15	4.5

	Thickness	
	(ft)	(m)
7. Claystone, greenish-gray to gray. Silty throughout, weathers to soft, silty soil. Satin spar veins common. Calcareous	7	2.1
6. Sandstone, thin-bedded, white to light-gray, fine- to medium-grained, chiefly well-rounded quartz. Calcareous cement	4	1.2
5. Claystone, gray or olive-green and yellow, sandy throughout, massive to poorly stratified. Occasional calcareous nodules and some selenite crystals. Exposures poor	15±	4.5±
4. Sandstone, dark-brown, fine- to medium-grained, chiefly quartz grains. Resistant, a prominent ledge-former at least locally. Massive bedding	6	1.8
3. Concealed. Restricted outcrops expose drab-gray or gray-green claystone or sandstone. Sandstones poorly cemented or restricted lenses. This part of the section forms low-angle slopes with thick weathered mantle	58±	17.7±
2. Sandstone, gray, fine-grained and calcareous. Thin-bedded, except for uppermost 1 to 3 feet (0.3 to 0.9 m), which is massive and moderately resistant. Some glauconite, but quartz is dominant clastic element	11	3.3
SUNDANCE FORMATION:		
1. Shale, sandy, glauconitic, thin-bedded and fissile, calcareous. No marine shells at this level, but abundant approximately 40 feet (12 m) below in coarse glauconitic sand	Not measured	

SECTION 9 - TENSLEEP, WYOMING

Measured across the nearly vertical section 1 mile (1.6 km) due west of Tensleep on the west side of Nowood Creek, north of U.S. 16, SW1/4 Sec. 24, T.47 N., R.88 W., Washakie County, Wyoming.

SYKES MOUNTAIN FORMATION:		
9. Sandstone, thin-bedded, light-gray, weathering brown. Some cross-laminations, ripple marks		

	Thickness (ft)	(m)
and fucoidal markings common, fine- to medium-grained, chiefly quartz. Iron-stained. Grades into dark-gray and black shale and thin-bedded sandstone lamina. (= Greybull sandstone; Sykes Mountain Formation in part, ?; Unit VIII of this report)..	8- 10	2.4- 3.0
CLOVERLY FORMATION:		
8. Claystone, dark-gray, weathers light gray, silty, unstratified. Some carbonized plant remains and occasional polished pebbles (= part of Himes Member, Cloverly Formation?; middle clay member of Darton's Cloverly Formation; part of Unit VII of this report)........................	21	6.4
7. Sandstone, light-gray to yellow, weathers brown or tan, fine-grained, siliceous. Massive bedding. (= part of Unit VII of this report)................	2	0.6
6. Claystone, variegated, gray, green, lavender, red-brown, unstratified, silty throughout. Polished pebbles moderately abundant. (= part of Unit VII of this report)..................................	31	9.4
5. Sandstone, fine to coarse-grained, conglomeratic locally, particularly in lower third. Brilliant white, sparkly, to light-gray. Quartz and white chert abundant, some feldspar. Massive bedding, frequent cross-laminations, well-indurated. Prominent ridge-former. (= lower sandstone of Darton's Cloverly Formation; Otter Creek Sandstone; Unit VI of this report)..................................	61	18.6
MORRISON FORMATION?		
4. Claystone, variegated, greenish to yellow-tan in upper part, orange to pale-red in lower part. Unstratified, nonfissile. Several 3 to 8 inch (7.5 to 20 cm) sandstone and siltstone lenses, yellow or tan in color. No chalcedony or barite concretions evident. (= Unit III? of this report)............	75	22.8
3. Sandstone, yellow to white, medium-grained, chiefly quartz and white chert. Some cross-laminations, massive bedding. Friable. (= Unit II? of this report)...	12	3.6

Thickness (ft) (m)

2. Claystone, yellow to greenish-gray, silty or sandy throughout. Occasional thin yellow or buff sandstone lenses. Claystone unstratified, calcareous. No chalcedony or limestone concretions. Partly concealed. (= Unit I? of this report)............ 130 39.6

SUNDANCE FORMATION:

1. Shale, greenish-gray, fissile, with thin sand lamina. Marine invertebrates abundant.......... Not measured

SECTION 10 - HYATTVILLE, WYOMING

This section was measured on the east limb of the Hyattville Anticline, at the north end of the prominent ridge 0.75 mile (1.2 km) southwest of Hyattville. N 1/2 Sec. 12, T. 49 N., R. 90 W., Big Horn County, Wyoming.

SYKES MOUNTAIN FORMATION:

7. Sandstone, yellow-brown or "rusty", thin-bedded with thin interbeds of dark fissile shale. Medium-grained, quartz, with abundant ripple marks and fucoids. Hematite-staining and ironstone lamina. A ledge-former. Overlain by black shale. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)........................ 7 2.1

CLOVERLY FORMATION:

6. Claystone, variegated, maroon to red-brown, purple-gray in lower part. Unstratified, sandy in part. Polished pebbles common. Chalcedony and barite concretions lacking. Locality YPM 66-3 is located in the lower third of this claystone. (= Himes Member, Cloverly Formation?; middle shale member of Darton's Cloverly Formation; Unit VII of this report). 39 11.9

5. Sandstone, white to light-gray, massive, medium-grained, chiefly quartz with some feldspar, mica and dark chert. (= Otter Creek Sandstone?; Unit VI? of this report).................................. 1-3 0.3-0.9

		Thickness (ft)	(m)
4.	Claystone, variegated, brightly colored, red, deep-maroon, red-brown and gray. Upper 20 feet (6 m) chiefly pastel or light-gray weathering to "popcorn" surface. Sandy in places, bentonitic in upper half. Chalcedony and barite concretions frequent in upper 35 to 40 feet (10.5 to 12.2 m), but appear to be absent below. (= Little Sheep Mudstone Member, Cloverly Formation?; Units V and perhaps ?III of this report)................................	74	22.5
MORRISON FORMATION:			
3.	Sandstone, white to light-gray, massive, fine- to medium-grained. Chiefly quartz with some white chert and feldspar. No conglomeratic or pebbly zones found. Well-cemented, a prominent ridge-former (= Unit II of this report).......	31	9.4
2.	Concealed beneath valley alluvium. Thickness appromimate................................	68±	20.7±
SUNDANCE FORMATION?			
1.	Sandstone, glauconitic, coarse-grained and highly calcareous. Thin-bedded. Poorly exposed. No marine invertebrates found in situ, but fragments of Gryphaea and belemnites are scattered on surface.........................	Not measured	

SECTION 11 - SHELL, WYOMING

This section was measured in the badlands 2 miles (3.2 km) southwest of Shell, Wyoming. N 1/2 Sec. 4, T.52 N., R.91 W., Big Horn County, Wyoming.

		Thickness (ft)	(m)
SYKES MOUNTAIN FORMATION:			
12.	Sandstone, massive, 1 to 2 foot (0.3 to 0.6 m) beds, tan to yellow-brown, considerable hematite staining and some ironstone concretions and thin lamina at top. Medium- to fine-grained, quartz. Ripple marks common, some fucoidal markings. Weathers into rectangular blocks. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report).........	10-12	3 - 3.6

CLOVERLY FORMATION:

		Thickness (ft)	Thickness (m)
11.	Claystone, variegated, orange, red-brown and maroon, yellow near top. Gray to purple-gray on fresh surfaces with some green mottling. Sandy throughout. Polished stones or "gastroliths" common. Unstratified. Two localities (YPM 62-4 and 62-5) are located in the lower part of this claystone. (= middle shale member of Darton's Cloverly Formation: Himes Member, Cloverly Formation; Unit VII of this report)	77	23.5
10.	Sandstone, very thin or absent. Five to 6 feet (1.5 to 1.8 m) thick at nearby exposures 300 yards (270 m) to north and west. Massive, cross-laminated, generally friable, but well-cemented at some localities. Medium- to coarse-grained, chiefly quartz and feldspar, some dark minerals and white chert. (= lower sandstone of Darton's Cloverly Formation; Unit VI of this report)	0-6	0-1.8
9.	Claystone, variegated, dark-gray, pale-purple to nearly white at top. Dark-gray on fresh surfaces. Massive, breaks into irregular chips. Bentonitic, weathers to "popcorn" surface. Limestone and chalcedony concretions abundant. Thin, white, discontinuous limestone lenses common, especially to the north of section site. Locality YPM 62-6 is situated near the base of this unit. (= part of Little Sheep Member, Cloverly Formation; part of Unit V of this report)	36	11
8.	Fragmental tuff, white, fine-grained with infrequent 1 to 3 mm fragments. Massive, weathers to irregular, bright-white, knobby masses. Forms distinct ledge	3	0.9
7.	Claystone, variegated, rose to Indian-red, dark red-brown and dark-gray. Massive and silty throughout. Occasional thin, white limestone lenses. Chalcedony and barite concretions and selenite crystals abundant. (= part of Little Sheep Mudstone Member, Cloverly Formation; part of Unit V of this report)	42	12.8

	Thickness	
MORRISON FORMATION:	(ft)	(m)
6. Sandstone, yellow to orange-brown, white on fresh surfaces, massive. Medium to coarse-grained with prominent cross-laminations. Well-cemented at most exposures, but tends to be friable at some sites. Quartz and white chert constitute 99% of grains. Weathers to smooth, rounded surfaces, little jointing. (= Unit II? of this report)................................	25	7.6
5. Claystone, light-gray to blue-gray, dark-gray on fresh surface. Massive and nonresistant. Calcareous in part. Chalcedony and gypsum rare or lacking. (= part of Unit I of this report)........	33.5	10.2
4. Sandstone, massive, and strongly cross-laminated. White or light-gray. Almost complete lack of jointing, weathering into large rounded masses.......	11	3.3
3. Claystone, pale-greenish-gray to yellow-gray. Poorly exposed but appears to be unstratified and not fissile. Color reminiscent of Sundance shales, but no marine fossils noted. Tentatively placed in Morrison. (= Unit I? of this report).............	30±	9.1±
2. Concealed, presumed to be similar to #3 above...	20±	6.1±
SUNDANCE FORMATION:		
1. Sandstone and shale, interbedded. Sands coarse and rich in quartz, glauconite and calcite. Shale, greenish, thinly stratified and fissile. Some levels nearly coquinoid........................	Not measured	
Concealed.		

SECTION 12 - SHELL CREEK DOME

Measured in "Devils Kitchen", 0.25 mile (0.4 km) north of Shell Creek, 6 miles (9.6 km) northeast of Greybull, Wyoming. NE 1/4 Sec. 31, T. 53 N., R. 92 W., Big Horn County, Wyoming.

	Thickness (ft)	(m)
SYKES MOUNTAIN FORMATION:		
4. Sandstone, buff, weathering yellow or tan, massive bedding, well-indurated, medium-grained, becoming thin-bedded upward with increasing rusty to red-brown, overlain by ironstone-bearing sandstones interbedded with black fissile shale. (= Greybull sandstone, Sykes Mountain Formation in part; Unit VIII of this report)............	5	1.5
CLOVERLY FORMATION:		
3. Claystone, variegated, gray, weathers tan in upper 20 feet (6.0 m), lower 40 feet (12 m) mottled gray-green and maroon, weathering red brown, speckled red, silty, polished pebbles abundant, nonbedded to poorly stratified, forms steep-rilled slopes. (= Himes Member in part, Cloverly Formation; Unit VII of this report)........................	59	18
2. Sandstone, yellow, olive, to green, weathering to green, locally brown. Coarse-grained somewhat friable quartz, feldspar in subangular grains, weathers into rounded knobs or pinnacles. Cross-laminated. Locality YPM 62-10 is situated in the upper few feet of this sandstone. (= Himes Member in part, Cloverly Formation; Unit VI of this report)...................................	13-15	3.9-4.5
1. Claystone, dark-gray, weathering nearly white, bentonitic, abundant chalcedony concretions, poorly stratified, breaks into irregular chips. Largely concealed. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report).	> 9	> 2.7
Concealed.		

SECTION 13 - CLOVERLY TYPE SECTION

Measured at prominent bluffs along west side of Orville Leavett's reservoir on Fenton Draw, NW 1/4 Sec. 24, T. 54 N., R. 92 W., Big Horn County, Wyoming. There can be no doubt that these exposures are those which Darton measured and used as the basis for proposing the Cloverly Formation (Darton, 1906: p. 52). The Cloverly Post Office, upon which the name was based, was situated approximately 0.75 mile (1.2 km) to the east.

Thickness
(ft) (m)

SYKES MOUNTAIN FORMATION:

7. Sandstone, gray and yellow-brown, weathering buff to brown, fine- to medium-grained, silty, massive bedding, becoming thinly bedded at top and interbedded with fissile black shale. Ripple marks common. Fucoids. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)................................. 12 3.6

CLOVERLY FORMATION:

6. Claystone, variegated, gray, tan, chocolate-brown, maroon to purple and rusty-yellow. Generally light- to medium-gray on fresh surfaces with green-gray mottling. Silty throughout with occasional sand lenses. Massive or unstratified, except for some fissile, dark shale lenses 2 to 4 inches (5 to 10 cm) thick in lower 15 feet (4.5 m). Lower 30 feet (9 m) forms steep, fluted slopes. "Gastroliths" or polished stones dispersed throughout, but most abundant in middle 20 feet (6 m), (= middle shale member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report)................................. 48 14.6

5. Sandstone, maroon, medium-grained, chiefly hematite-stained quartz grains. Weathers to chocolate brown. Massive. (= part of Unit VI of this report)................................. 3.5 1.1

4. Sandstone, yellow to olive-green, weathers to yellow-brown or maroon brown near top. Coarse-grained, angular grains of quartz, feldspar and some dark minerals, pebbly in places. Has distinctive "salt and pepper" appearance. Massive and strongly cross-laminated. Isolated dinosaur bone fragments occur infrequently throughout the upper 10 to 15 feet (3 to 4.5 m) of this sandstone. (= lower sandstone of Darton's Cloverly Formation; Unit VI of this report)........................... 39 11.9

3. Claystone, dark- to medium-gray, weathers to light gray or nearly white. Bentonitic, weathers into low-rounded, vegetation-free mounds with "popcorn" surfaces. Chalcedony, barite and calcareous concretions very abundant, selenite crystals and satin spar

	Thickness	
	(ft)	(m)
common. (= Little Sheep Mudstone Member, Cloverly Formation, in part; Unit V of this report in part)......................................	35±	10.6±
2. Fragmental tuff, light-gray, weathers brilliant white and forms low-rounded mounds or benches. Unstratified and very fine-grained with rare 2 to 3 mm fragments. Very conspicuous white chalky-looking band below vivid Cloverly bluffs. (= Little Sheep Mudstone Member, Cloverly Formation in part; Unit V of this report in part)...............	3	0.9
1. Claystone, dark- to medium-gray, weathers to dark gray green. Unstratified, bentonitic, weathers to low angle "popcorn" slopes. Chalcedony and barite concretions present, but not common. Base concealed. (= Little Sheep Mudstone Member, Cloverly Formation in part; Unit V of this report in part)......................................	-	-

Concealed.

SECTION 14 - CEDAR CREEK

Section 14 was measured in the exposures of the two prominent buttes approximately 2 to 2.5 miles (3.2 to 4 km) northeast of the former Cloverly Post Office site, 3.5 miles (5.6 km) east of the type exposures. The best exposures are just south of Cedar Creek and east of the junction between Cedar and Beaver Creeks. NW 1/4 Sec. 17, T.54 N., R.91 W., Big Horn County. Wyoming. This section is considered critical to the general interpretations and correlations presented in this report because: a) it includes more of the continental sequence than do the type exposures 3 miles (4.8 km) to the west; b) it includes a conglomeratic unit which is identical in lithology and stratigraphic position with the typical Pryor Conglomerate facies to the north; c) the level of this conglomerate clearly establishes that it is not an extension of the basal, sometimes conglomeratic sandstone described by Darton (1906).

SYKES MOUNTAIN FORMATION:

12. Sandstone, thin-bedded to massive, yellow-brown or "rusty"-colored, fresh surfaces buff. Medium- to fine-grained, well-rounded quartz grains with hematite staining. Ripple marks common on nearly all bedding planes. Forms a resistant cap rock.

		Thickness	
		(ft)	(m)
	Overlain by "rusty"-weathering, black, fissile shale with thin sandstone and ironstone laminae. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)............	6	1.8
CLOVERLY FORMATION:			
11.	Claystone, variegated, gray, red-brown, maroon, fresh surfaces purple-gray. Silty, with several thin, brown sandstone lenses. Polished pebbles common. Forms steep, fluted or rilled surfaces conspicuous by their bright colors. (= middle member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report)...................................	42	12.8
10.	Sandstone, olive to straw-yellow on weathered surfaces, yellow on fresh surfaces. Massive, coarse-grained, small (0.25 to 0.5 inch [0.7 to 1.5 cm]) pebbles locally. Chiefly subangular quartz and feldspar, some quartzite, white chert and dark minerals. Friable, breaks down easily, forms steep, smooth-rounded and rilled surfaces, often partly concealed. Prominent cross-laminations. One to 2 miles (1.6 to 3.2 km) to the north, becomes much thicker and well-indurated, forming high, blocky, cliffed exposures, usually red to yellow. (= lower sandstone member of Darton's Cloverly Formation; Unit VI of this report).......	35	10.6
9.	Claystone, weathers light- to dark-gray, fresh surfaces dark-gray. Massive, bentonitic, weathers to "popcorn" surfaces. Chalcedony and barite concretions abundant. (= part of Little Sheep Mudstone Member, Cloverly Formation; part of Unit V of this report).......................	11	3.3
8.	Fragmental tuff, white, fine-grained with medium-sized fragments, light-gray on fresh surfaces. Weathers to prominent bright white and persistent knobby ledge. (= part of Unit V)...............	2	0.6
7.	Claystone, variegated, orange, gray-purple, dark- and light-gray. Poorly stratified, bentonitic, weathers to extensive low-angle, vegetation-free, "popcorn" slopes. Chalcedony and barite concretions common,		

		Thickness (ft)	(m)
	very abundant in lower and upper 20 feet (6 m). Selenite crystals and satin spar common. Abundant, unidentifiable bone fragments occur locally in the upper 10 to 20 feet (3 to 6 m) of this claystone. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	58	17.7
6.	Claystone, variegated, white, light-gray, gray-green. Massive, sandy. No chalcedony or gypsum. (= part of Unit V?of this report)	8	2.4
5.	Sandstone, white to light-brown, coarse-grained, quartz. Cross-laminations, massive bedding. Locally very friable	2-4	0.6-1.2
4.	Claystone, light-gray to nearly white. Unstratified, sandy. Nonresistant, partly covered. Very similar to #7. Chalcedony concretions apparently absent. (= part of Unit V? of this report)	18	5.5
3.	Conglomerate and sandstone, dark-gray to brown. Massive throughout with prominent cross-laminations, upper 15 feet (4.5 m) very coarse containing pebbles up to 0.5 inch (1.2 cm). Chiefly quartz, dark-gray chert, brown chert and some white chert (?), subangular to moderately rounded. Lower 3 to 5 feet (0.9 to 1.5 m) light gray to tan and non-pebbly, medium-grained sandstone, white chert and quartz grains predominate. Entire unit only moderately well-cemented, but still forms resistant ledge. The conglomeratic facies resembles typical Pryor Conglomerate lithology, but not as coarse-grained. Equated with Unit IV of this report. Lower sandstone not separated from conglomerate by any clear, persistent physical break at these exposures, but superficially resembles Unit II as exposed in the Thermopolis area	18	5.5
MORRISON FORMATION:			
2.	Claystone, variegated, light- to dark-gray, becoming pink to pale-purple in upper 20 to 25 feet (6 to 7.5 m). Medium-gray on fresh surfaces, throughout. Thin, discontinuous sandstone lenses frequent. Chalcedony and barite concretions abundant, some selenite and white satin spar. Calcareous and sandy. Base concealed. The famous Howe Quarry		

Thickness (ft) (m)

of the American Museum occurs near the middle of this claystone. (Tentatively assigned to Unit III of this report, but may be part of Unit I).... 91 27.7

1. Concealed interval, thickness in excess of 45 feet (13.7 m)............................ >45 >13.7

SUNDANCE FORMATION:

Sundance Formation not exposed in the vicinity of these exposures, but interbedded calcareous, glauconitic and coquinoid sandstones and shales are exposed beneath this sequence approximately 2 miles (3.2 km) to the southeast. Precise level below #2 above not determined, but concealed interval estimated at 45 to 75 feet (13.7 to 23 m).. Not measured

SECTION 15 - CRYSTAL CREEK

This section was measured in exposures along the south side of the South Branch of Crystal Creek, approximately 0.75 mile (1.2 km) southwest of the upstream limit of Cloverly outcrop. Sec. 8(?), T. 55 N., R. 92 W., Big Horn County, Wyoming.

SYKES MOUNTAIN FORMATION:

4. Sandstone and shale, interbedded. Thin-bedded, ripple-marked, dark- to "rusty"-brown, fine-grained sandstone, heavily coated with dark hematite alternating with thin seams of paper-thin, fissile, dark-gray to black shale. Selenite crystals and satin spar common in shale interbeds. Ironstone concretions frequent at top. Overlain by "rusty"-weathering, black shale. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)...................................... 13 3.9

CLOVERLY FORMATION:

3. Claystone, variegated, yellow to gray, red-brown, maroon and deep-purple, generally mottled, purple-gray to gray-green on fresh surfaces. Sandy throughout, but occasional sandstone lenses 2 to 8 inches (5 to 20 cm) are present. Ironstone concretions

	Thickness	
	(ft)	(m)
present at top, polished pebbles or "gastroliths" frequent at all levels, selenite and satin spar frequent in lower 35 feet (10.6 m). Lower half forms steep, fluted slopes. Petrified wood occurs locally at about 15 to 20 feet (4.5 to 6 m) above base. Light-gray, bentonitic zone 4 to 5 feet (1.2 to 1.5 m) thick conspicuous at 12 feet (3.6 m) above base. (= middle shale member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report)	52	15.8
2. Sandstone, yellow to nearly white, weathers buff to yellow, locally pink. Fine- to medium-grained, well-sorted and rounded grains chiefly of quartz, white chert and some feldspar. Weathers into large rectangular blocks, massive bedding, some cross-lamination. (= lower sandstone member of Darton's Cloverly Formation; Unit VI of this report)	27	8.2
1. Claystone, light- to dark-gray, weathers to light gray. Bentonitic, weathering to low-rounded hills with "popcorn" surfaces. Some chalcedony concretions and veins. Base concealed. (= part of Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	> 28	> 8.5

Concealed.

SECTION 16 - ALKALI CREEK

This section was measured across the Cloverly-"Rusty Beds" hogback of the east limb of Little Sheep Mountain Anticline, just north of the westernmost of three small reservoirs on Alkali Creek, 5 miles (8 km) east of Himes, in SE 1/4 Sec. 30, T. 55 N., R. 93 W., Big Horn County, Wyoming.

SYKES MOUNTAIN FORMATION:

8. Sandstone, gray, weathering buff to rusty yellow, coarse-grained, cross-laminated, massive-bedding, iron-stained, ironstone concretion layers prominent near top. Polished pebbles at base. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)	9.5	2.9

CLOVERLY FORMATION:	Thickness (ft)	Thickness (m)
7. Claystone, gray, weathers buff at base, becoming red to maroon toward the top. Sandy, massive bedding, forms steep fluted slopes. Polished pebbles. (= part of middle shale member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report)........................	17.5	5.3
6. Sandstone, tan to gray, weathers to buff brown, gray streak near top, massive, medium-grained, chiefly well-rounded quartz. Some cross-lamination......................................	5	1.5
5. Claystone, light-gray, weathers to buff with maroon mottling. Colors subdued compared with other localities. Polished pebbles common. (= Himes Member Cloverly Formation; Unit VII of this report).	28.5	8.7
4. Sandstone, white, weathers white to very light tan, massive, strongly cross-laminated, medium-grained, sparkly, very high quartz content...............	5	1.5
3. Sandstone, yellow to brown, weathers to gray, some brown and maroon mottling, coarse-grained with clay, becoming finer-grained at top, massive, occasional cross-laminations. Base concealed. (= Unit VI of this report)..................................	37±	11.3±
2. Concealed interval................................	15±	4.5±
1. Claystone, variegated, light- to dark-gray, grading downward to pale and deep purple and maroon. Bentonitic, forms extensive soft "popcorn" surfaces. Chalcedony and barite concretions very abundant, some satin spar. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report).................................	38±	11.6±

Concealed.

SECTION 17 - SHEEP MOUNTAIN

Measured across the east-facing exposures on the west limb of Sheep Mountain Anticline, 1.25 miles (2 km) west of the bentonite plant at the west entrance to Bighorn Canyon. SE 1/4 Sec. 3, T. 53 N., R. 94 W., Big Horn County, Wyoming.

	Thickness	
SYKES MOUNTAIN FORMATION:	(ft)	(m)
9. Sandstone, yellow to rusty-brown, buff on fresh surfaces. Massive bedding, cross-laminations, few ripple marks. Medium-grained, well-rounded quartz. Hematite staining. Overlain by thin dark-brown sandstone strata, interbedded with fissile black shale, weathering rusty color. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)........................	4- 6	1.2- 1.8
CLOVERLY FORMATION:		
8. Claystone, variegated, red, maroon, purple and bluish-gray. Massive or unstratified, weathering to steep fluted slopes. Occasional discontinuous sand lenses, usually friable. Polished stones or "gastroliths" common. Localities YPM 62-11, 62-12, and 62-13 are situated near the top of this unit. (= middle shale member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report)................................	32	9.7
7. Sandstone, white on fresh surface, weathering to light brown. Massive to thin-bedded, generally well-cemented. Fine- to medium-grained subangular quartz, feldspar, some white chert and dark minerals. (= Unit VI? of this report)............	2	0.6
6. Claystone, variegated, yellow, rose, rose-gray to light-gray or white. Unstratified, bentonitic, weathering to low angle slopes with "popcorn" surfaces, soft and collapsible. Chalcedony and barite concretions very abundant, selenite and pink and orange satin spar common. Occasional discontinuous, thin sandstone lenses. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)......................................	103	31.4
5. Sandstone, tan to gray, gray on fresh surface. Massive parallel stratification. Cross-laminations conspicuous. Coarse-grained, quartz with some light-gray and yellow chert. Pebbles extremely rare. (= Unit IV? of this report).........	8	2.4

MORRISON FORMATION: Thickness (ft) (m)

4. Claystone, variegated, yellow-gray, dark-gray, to rose-pink. Thin, discontinuous, tan sandstone lenses just above middle of sequence. Chalcedony and barite concretions abundant in lower half, but gypsum apparently absent. Massive or poorly stratified, weathers into low, sandy slopes. (Presence of chalcedony suggests assignment to Unit V, but on the basis of a very similar lower claystone bearing similar concretions which underlies a dark conglomerate believed to be the Pryor Conglomerate in Section 14 at Cedar Creek, I have tentatively referred this to Unit III). . 109 33.2

3. Sandstone, brown, light-brown on fresh surface. Massive, parallel stratification. Fine-grained quartz. 2-4 0.6-1.2

2. Claystone, partly concealed, predominantly yellow-gray to light-gray and sandy. Nonresistant and calcareous. Occasional 2 to 3 inch (5 to 7.5 cm) sandstone layers. (Presumed to equal part of Unit I of this report). . . . . 45± 13.7±

SUNDANCE FORMATION:

1. Sandstone, gray-green, coarse, glauconitic and containing shell fragments. Surface littered with Gryphaea fragments less than 10 feet (3 m) below the contact with # 2. . . . . Not measured

SECTION 18 - LITTLE SHEEP MOUNTAIN

Measured across the hogbacks on the west limb of Little Sheep Mountain Anticline, 1.5 miles (2.4 km) south of U. S. 14 Alternate, 4 miles (6.4 km) east of Lovell, Wyoming. NE 1/4 Sec. 21, T. 56 N., R. 95 W., Big Horn County, Wyoming.

SYKES MOUNTAIN FORMATION:

6. Sandstone, orange-brown, with much dark iron staining. Massive, parallel and cross-stratification, and frequent ripple marks. Medium- to fine-

	Thickness (ft)	(m)
grained, chiefly well-rounded quartz. Ironstone concretions common at top and in overlying dark-gray fissile shales and sandstone. (= Sykes Mountain Formation in part; Greybull sandstone; Unit VIII of this report)........................	6	1.8
CLOVERLY FORMATION:		
5. Claystone, variegated, maroon to red-brown, becoming yellow-brown near top. Gray-green with purple and red mottling on fresh surfaces. Unstratified, sandy throughout. Polished pebbles rare. (= part of middle shale member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report)............................	15	4.5
4. Sandstone, gray, weathers tan. Coarse-grained, chiefly quartz with some feldspar as subangular grains. Massive and resistant................	3	0.9
3. Claystone, gray, weathers tan to red brown and maroon, unstratified and sandy throughout. Several massive 3 to 8 inch (7.5 to 20 cm) sandstone lenses. Polished pebbles present, but not abundant. Forms bright-colored, steep, fluted slopes. Base concealed. (= part of middle shale member of Darton's Cloverly Formation: Himes Member, Cloverly Formation; Unit VII of this report).......	43	13.1
2. Concealed interval	34±	10.3±
(Approximately 0.25 mile (0.4 km) to the south of this site, a 4 to 8 foot (1.2 to 2.4 m) massive sandstone crops out at what appears to correspond to this concealed interval (#2) in this Section. Exposures here are poor, though, so adjacent units could not be established. The general character of this sandstone [yellow-brown to almost olive color, medium-grained, rich in subangular quartz, feldspar with some dark grains] is comparable to that of Unit VI in the vicinity of the Cloverly Post Office site.)		
1. Claystone, dark-gray, weathers light gray to pale purple. Massive. Bentonitic, weathering into soft, low-angle slopes with "popcorn"-like surface. Chalcedony concretions abundant, some selenite crystals and white satin spar. Base concealed. (= part of Little Sheep Member, Cloverly Formation?; Unit V of this report).................................	>24	>7.3
Concealed.		

SECTION 19 - SYKES MOUNTAIN

Composite section measured on the southwest flank and in exposures in the prominent gorge through the southwest flank of Sykes Mountain, approximately 2.5 miles (4 km) southeast of State secondary highway #0208 to the Big Horn Recreation Area at Horseshoe Bend. S 1/2 Sec. 11, T. 57 N., R. 95 W., Big Horn County, Wyoming.

	Thickness	
SYKES MOUNTAIN FORMATION:	(ft)	(m)
11. Sandstone, rusty-brown to dark-brown, tan on fresh surfaces. Massive to thin-bedded, ripple marks abundant. Medium- to fine-grained quartz in rounded grains. Six inches (15 cm) to several feet of dark fissile shale beneath lowest sandstone and thin shell interbeds with predominantly sandstone facies. Overlain by dark fissile shales and 0.5 to 2 inch (1.2 to 5 cm) sandstone layers with frequent ironstone concretions. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)	11	3.3
CLOVERLY FORMATION:		
10. Claystone, variegated, red-brown, maroon, purple-gray, becomes rusty near top. Occasional, white to light-gray, discontinuous zones 2 to 5 feet (0.6 to 1.5 m) thick. Massive or poorly stratified, generally light-purple-gray on fresh surfaces, breaks into irregular, slickensided blocks. Some dark-green mottling on fresh surfaces. Sandy throughout. Polished pebbles abundant. (= middle shale member of Darton's Cloverly Formation; Himes Member, Cloverly Formation; Unit VII of this report).	53	16.1
9. Sandstone, white to tan or light-brown, becoming "fire"-red in upper part locally. Generally buff to yellow-tan on fresh surfaces. Medium- to coarse-grained, chiefly angular to subangular grains of quartz, feldspar and white chert. Massive, parallel- and cross-laminations. Not conglomeratic. Forms smooth, high, resistant cliffs. (= Unit VI of this report)	81	24.7
8. Claystone, variegated, purplish-red or maroon in lower two thirds, gray in upper third. Bentonitic, calcareous and sandy, several discontinuous sand		

	Thickness	
	(ft)	(m)
lenses up to 10 inches (25 cm) thick. Chalcedony and barite concretions very abundant, gypsum apparently absent. Unstratified and nonresistant. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	75	22.8
7. Conglomerate, sandy with abundant pebbles up to 1 inch (2.5 cm) in diameter. Gray, weathering to dark-gray and gray-brown. Black and dark-brown chert predominate, some yellow chert and light-colored quartzite. Grains and pebbles well rounded. Parallel and cross-laminations. (= Pryor conglomerate; Unit IV of this report)	45	13.7
MORRISON FORMATION:		
6. Sandstone, tan to light-brown, fine- to medium-grained. Pebbles rare. Chiefly well-rounded grains of quartz and light-colored chert. Cross-laminations common, massive bedding. (This unit clearly separable on lithic character and by a conspicuous irregular break from overlying conglomerate. Tentatively equated with Unit II in this report)	62	18.9
5. Claystone, greenish-gray, bentonitic, unstratified and nonresistant, often concealed beneath fallen blocks and talus of overlying sandstone and conglomerate that litter most lower slopes. (= part of Unit I? of this report)	21±	6.4±
4. Sandstone and shale interbedded. Sandstones tan to yellow, from 6 inches to 2 feet (15 to 60 cm) thick, apparently rather persistent. Shales, thinly bedded and fissile, gray on fresh surfaces, weathering tan. (= part of Unit I? of this report)	16	4.9
3. Claystone, yellow to gray-green, fresh surfaces pale-green — almost olive in color. Massive or unbedded. Sandy at some levels. Chalcedony and gypsum absent. Calcareous throughout. (Unit I of this report)	34	10.3
2. Sandstone, tan, massive, resistant and conspicuous ledge-former. Medium-grained quartz well-cemented with calcite	3	0.9

	Thickness (ft)	(m)
1. Claystone, yellow to pale-green, weathering predominantly yellow. Forms low-angle, soft slopes. No concretions or gypsum. Calcareous locally. Base concealed. (= part of Unit I of this report)	> 24	> 7.3

Concealed.

SECTION 20 - CROOKED CREEK

Section measured across series of cuestas and ridges between Crooked Creek on the west and the Dryhead road on the east, approximately 1.5 miles (2.4 km) south of the Montana State line. W 1/2 Sec. 27 and N 1/2 Sec. 28, T. 58 N., R. 95 W., Big Horn County, Wyoming. The upper part of the sequence is in the immediate vicinity of Yale Localities YPM 63-20 and 22.

	Thickness (ft)	(m)
SYKES MOUNTAIN FORMATION:		
21. Sandstone, light-gray, weathers tan to light orange, massive, well-indurated, medium-grained, strongly cross-laminated, thin-bedded and fine-grained at base. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)	8	2.4
CLOVERLY FORMATION:		
20. Claystone, gray, yellow-brown and brown; weathers light yellow brown (rusty), large to small ironstone concretions, poorly stratified to massive, silty throughout. (= Himes Member in part? of Cloverly Formation; part of Unit VII of this report).	11.5	3.5
19. Siltstone, olive, weathering tan, thin-bedded, well-cemented, becoming more massive and coarser-grained at the base, brick-red and brown mottling, gypsum (satin spar) seam at base. (= Himes Member in part of Cloverly Formation; part of Unit VII of this report)	5.5	1.7
18. Claystone, variegated yellow to olive, weathering gray maroon and red, mottled, silty in lower third. (= part of Himes Member, Cloverly Formation; Unit VII of this report)	10	3

		Thickness	
		(ft)	(m)
17.	Sandstone, white, medium-grained, rounded quartz grains, friable, cross-laminated, massive bedding. (= Himes Member, in part, of Cloverly Formation; part of Unit VII of this report)..................	4	1.2
16.	Claystone, variegated dark to light-gray, with green and red-brown mottling; weathers brown, red brown, maroon, massive, silty becoming sandy at base. Forms steep, irregularly fluted slopes. Fresh material breaks into irregular slickensided blocks. Fossil bone at base. Localities YPM 63-17, 63-18, 63-19 and 63-20 produced bone from the lower part of this claystone. Polished pebbles common, but not abundant and not closely associated with fossil bone. (= part of Himes Member, Cloverly Formation; Unit VII of this report)...................	41	12.5
15.	Sandstone, light-gray to green, coarse- to medium-grained, massive, cross-laminations. YPM localities 63-17, 63-18, 63-19 and 63-20 produced bone from nearly all levels in this sandstone. (= part of Himes Member, Cloverly Formation; part of Unit VII of this report)	4	1.2
14.	Claystone, variegated dark-brick-red with green and yellow mottling, weathers brown, silty, moderate stratification. Some polished pebbles, but not closely associated with fossil bone. Localities YPM 63-18, 63-19, 63-27, and 63-28 produced fossil bone from several levels within this claystone. (= Himes Member in part, Cloverly Formation; part of Unit VII of this report)............	4	1.2
13.	Sandstone, gray to yellow-tan, weathers tan; irregular green and reddish clay seams, coarse-grained, quartz, feldspar and minor ferric minerals. Massive, resistant, strongly cross-laminated; pebbles and clay balls at base. Localities YPM 63-16 and 63-32 are situated near the top of this unit. (= Unit VI of this report)................	11.5	3.5
12.	Claystone, dark-gray to gray-green, weathers to light gray and pale purple. Fresh material breaks into irregular chips, bentonitic, satin spar; calcareous concretions rare. Chalcedony and barite concretions also rare. Forms low, rounded, vegetation-free slopes, surfaces soft and "popcorn"-like.		

		Thickness	
		(ft)	(m)
	Discontinuous 6 inch (15 cm) sandstone lenses, usually white or tan. Some fossil bone in upper 25 to 30 feet (7.5 to 9 m). Also petrified wood. Localities YPM 62-14, 63-22 and PU 49-1 occur in the upper third of this claystone. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	128	39
11.	Sandstone, brown, coarse-grained, well-rounded, sparkly quartz grains, well-cemented. Massive with some cross-laminations. Resistant, forms prominent, persistent ledge	2- 3	0.6- 0.9
10.	Claystone, variegated, rose-pink to light-purple. Breaks into irregular chips, poorly laminated. Calcareous. No chalcedony observed. (= part of Unit V of this report)	27	8.2
9.	Sandstone, conglomeratic in upper 15 to 18 feet (4.5 to 5.5 m). Medium-gray on fresh exposures, weathers dark gray to brown. Consists of coarse quartz and dark chert grains. Pebbles up to 0.75 inch (1.6 cm), chiefly dark chert and yellow or brown quartzite. Strongly cross-laminated. Massive beds, very resistant. Forms cap-rock of irregular, knobby and pedestal-marked surfaces, capping ridge west of Dryhead road. No distinct break between conglomerate and sandstone: gradational textural change. (= Pryor Conglomerate; Unit IV of this report)	28	8.5

MORRISON FORMATION:

8.	Claystone, weathers gray and pale green. Fresh surfaces medium-gray but with greenish cast. Generally sandy, but unstratified. Several 1 to 6 inch (2.5 to 15 cm) discontinuous sand lenses, especially in lower half. No chalcedony or gypsum observed. (= Unit III of this report)	51	15.5
7.	Sandstone, yellow-brown fresh and weathered. Massive, forming prominent cap-rock. Weathers into thick, smoothly rounded blocks. Medium- to fine-grained, quartz and light to nearly white chert. Cross-laminations throughout. (= Unit II? of this report)	17	5.2

		Thickness	
		(ft)	(m)
6.	Claystone, gray, weathers tan, poorly stratified, non-resistant. Forms low-angle slopes where not protected by overlying sandstone. Calcareous and silty, but no chalcedony, or limestone concretions, or gypsum observed. (= part of Unit I of this report)	27	8.2
5.	Sandstone, light-tan both fresh and weathered. Medium-grained, rounded quartz. Massive, parallel and cross-stratification. Resistant, weathers to smooth, rounded blocks and cliff surfaces. Very similar in appearance to # 7 above except white chert is rare or lacking. (= part of Unit I of this report)	21	6.4
4.	Claystone, gray, weathers pale yellow. Silty and calcareous. Rare selenite crystals observed, but not found *in situ*. Forms deeply weathered, low-angle slopes. (= part of Unit I of this report)	19	5.8
3.	Sandstone, weathers brown, tan on fresh surfaces. Blocky and massive in lower half, thin-bedded in upper part. Medium-grained, rounded quartz with calcareous and limonitic cement. (= part of Unit I of this report)	14	4.2
2.	Claystone, gray-green on fresh surfaces, weathers green to greenish tan. Partly concealed, but at least locally shows thin parallel-stratification. Not fissile. (Tentatively referred to Unit I, but may be upper part of Sundance Formation)	11	3.3

SUNDANCE FORMATION:

1.	Sandstone, brown, alternating massive and paper-thin parallel-stratification. "Paper-parting" of weathered exposures characteristic. Medium-grained quartz, some glauconite and calcareous throughout. No marine invertebrate remains found *in situ*, but surfaces near by are strewn with belemnites and *Gryphaea*	Not measured

SECTION 21 - GYPSUM CREEK

Section measured across east limb of Gypsum Creek Anticline, just north of the Warren road. SE 1/4 Sec. 22, T. 58 N., R. 96 W., Big Horn County, Wyoming.

		Thickness	
	SYKES MOUNTAIN FORMATION:	(ft)	(m)
11.	Sandstone, brown to orange, with dark, fissile shale interbeds. Fine-grained quartz. Abundant ripple marks and fucoidal impressions. Forms resistant ridge. Overlain by thin sandstone layers and dark fissile shale. (= Greybull sandstone?; Sykes Mountain Formation in part; Unit VIII of this report)	7	2.1
	CLOVERLY FORMATION:		
10.	Claystone, maroon to red-brown, some blue-gray, maroon and purple mottling on fresh surfaces. Unstratified. Sandy near base. Polished pebbles common throughout. Occasional gypsum (satin spar) seams. (= Himes Member, Cloverly Formation; Unit VII of this report)	21	6.4
9.	Sandstone, weathers buff to orange tan, yellow locally. Tan on fresh surfaces. Medium- to coarse-grained. Not conglomeratic. Chiefly quartz, some chert and feldspar. Cross-laminations pronounced. Massive and resistant, forms very prominent ridge. (= Unit VI of this report)	58	17.7
8.	Claystone, weathers to pastel rose and purple, purplish dark gray on fresh surfaces. Unstratified, breaks into irregular, waxy chips. Bentonitic and weathers to soft "popcorn" surfaces, generally free of vegetation. Chalcedony and barite concretions very abundant, satin spar and selenite crystals are also common. Occasional buff to white sandstone wedges up to 6 inches (15 cm) thick. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	112	34.1
7.	Sandstone, gray to light-brown, gray on fresh surfaces. Coarse-grained, angular to sub-rounded quartz, dark and light chert, and yellow quartzite?. Massive and very resistant—a ridge-former. Not		

	Thickness (ft)	(m)
conglomeratic at the site of this section, but several conglomeratic wedges occur in exposures to the north. Cross-laminations common and well-developed throughout full thickness. (Tentatively equated with Unit VI; = Pryor Conglomerate).......	46	14
MORRISON FORMATION:		
6. Claystone, variegated, pale-green and gray in upper 80 feet (24 m), gray, rose and orange in lower 60 feet (18 m). Medium- to light-gray on fresh surfaces. Sandy or silty throughout, prominent light-tan sandstone wedges and strata scattered throughout section, including a persistent 2 foot (0.6 m) massive sandstone at 58 feet (17.7 m) above base. Calcareous but lacks calcite, barite and chalcedony concretions. Gypsum also lacking. (= Unit III? of this report)....................	145	44.2
5. Sandstone, white to light-tan, white and sparkly on fresh surfaces. Chiefly rounded quartz with some white and dark chert in medium-sized grains. Cross-laminations frequent. Persistent, massive bedding. Moderately well-indurated, but surfaces friable. (= Unit II of this report)......................	19	5.8
4. Claystone, neutral-gray, medium to dark, poorly stratified and nonfissile. Chalcedony and calcite concretions apparently absent. (= part of Unit I of this report)..............................	56	17
3. Sandstone, yellow to gray, buff on fresh surfaces. Thin-bedded with ripple marks on upper bedding planes. Medium- to fine-grained. Concealed locally. (= part of Unit I of this report).........	5	1.5
2. Claystone, yellow to greenish-gray, medium-gray on fresh surfaces. Poorly exposed, but thinly stratified locally. Very sandy at base, and grades into green, glauconitic, thin-bedded sandstone beneath. May represent upper part of Sundance Formation. (Unit I of this report).........................	12	3.6
SUNDANCE FORMATION:		
1. Sandstone, greenish-gray, glauconite and quartz highly calcareous. Thin-bedded with occasional interbeds of fissile, sandy shale. Fragments of Gryphaea abundant 15 to 30 feet (4.5 to 9 m) down section, but infrequently noted in situ in these strata......................	Not measured	

SECTION 22 - RED DOME

Composite section measured in discontinuous hogbacks on south side of Red Dome, immediately north and south of the Bridger-Pryor road. S 1/2 Sec. 20, T. 7 S., R. 24 E., Carbon County, Montana.

	Thickness (ft)	(m)
SYKES MOUNTAIN FORMATION:		
12. Sandstone, dark, rusty-brown on weathered surfaces, light-brown on fresh surfaces. Thin and massive bedding, with some shale interbeds. Fine-grained, chiefly quartz with occasional dark grains. Ironstone concretions at top, upper strata with dark ironstone staining. Few ripple marks. (= Greybull sandstone?; Sykes Mountain Formation in part; Unit VIII of this report)........................	10.5	3.2
CLOVERLY FORMATION:		
11. Claystone, variegated, red-brown, maroon, purple-gray and gray, some rusty-yellow in upper 4 to 8 feet (1.2 to 2.4 m). Fresh surfaces green-gray with green and red-brown mottling. Sandy in lower half, massive throughout. Fresh rock breaks into irregular blocks with shiny slickensided surfaces. Polished stones or "gastroliths" common. Locality YPM 64-52 is situated near the middle of this unit. (= Himes Member, Cloverly Formation; Unit VII of this report)................................	65	19.8
10. Sandstone, yellow-brown, medium-grained, subangular quartz, feldspar and light-colored chert. Friable and poorly cemented. Massive with occasional cross-beds. (= Unit VI? of this report)....	3	0.9
9. Claystone, light-gray and blue-gray, generally medium-gray on fresh surfaces. Unstratified, breaks into irregular, "greasy" chips. Bentonitic, weathers to soft "popcorn" surfaces. Chalcedony concretions common, occasional seams of satin spar and selenite crystals. Infrequent, discontinuous sandstone lenses. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report).	64	19.5
8. Conglomerate, dark-gray and brown, fresh surfaces also dark-gray and brown. Coarse sand grains and subrounded pebbles up to 1 inch (2.5 cm) of quartz,		

	Thickness	
	(ft)	(m)
yellow to brown quartzite, black and brown chert. Massive bedding with frequent large cross-beds. Very resistant, forms massive vertical cliffs and prominent ridges, a cap-rock. (= Pryor Conglomerate; Unit IV of this report)...................	52	15.8
MORRISON FORMATION:		
7. Claystone, variegated, red-brown, green, yellow-gray, fresh surfaces predominantly gray-green. Unstratified, sandy and calcareous throughout. Several 3 to 6 inch (7.5 to 15 cm) sandstone lenses, well-indurated and resistant. Claystone, nonresistant, forms deep-weathered, silty-sandy slopes. Chalcedony and barite concretions apparently lacking. (= Unit III of this report).................	88	26.8
6. Sandstone, light-yellow to light- gray or white, nearly white on fresh surfaces. Some 6 to 15 inch (15 to 37.5 cm) strata but most of the unit is very thin-bedded — some of it extremely thin-bedded, weathering into "paper-thin" sheets. Medium-sized grains of quartz with some white chert. Occasional cross-beds, but no ripple marks. (Tentatively equated with Unit II in this report)........	17	5.2
5. Claystone, greenish-gray, fresh surfaces darker gray. Conspicuous light-gray and pink zone near the middle. Unstratified. Silty and calcareous throughout. Several discontinuous sandstone wedges just below the pink zone. No chalcedony. (= part of Unit I of this report)..................	75	22.8
4. Sandstone, yellow to light-tan, buff on fresh surfaces. Massive bedding, medium-grained, well-rounded quartz grains, firmly cemented with calcite. Sparkly on fresh surfaces................	6	1.8
3. Claystone, like unit #5 above, greenish-gray to yellow on weathered surfaces. Fresh surfaces dark to medium gray. Unstratified, and nonresistant, weathers to low-angle slopes. Silty and calcareous throughout. (= part of Unit I of this report).............	32	9.7
2. Concealed interval............................	15±	4.5±

	Thickness (ft)	(m)
SUNDANCE FORMATION:		
1. Thin-bedded, sandstone and shale. Medium-grained and calcareous. Shell fragments, some levels coquinoid. Glauconitic.................	Not measured	

Concealed.

SECTION 23 - MIDDLE FORK BRIDGER CREEK

This section was measured on the south-facing scarp directly across from the prominent pyramid-like butte, 0.5 mile (0.8 km) north of Middle Fork of Bridger Creek. NE 1/4 Sec. 17, T. 7 S., R. 24 E., Carbon County, Montana. Five Yale localities (YPM 64-57, 58, 74, 75 and 65-1) are within 200 yards (183 m) of this section site and three others, (YPM 64-53, 54 and 56) and probably one American Museum locality (AM 33-8) are 0.5 to 0.75 mile (0.8 to 1.2 km) distant.

	(ft)	(m)
SYKES MOUNTAIN FORMATION:		
10. Sandstone, buff, weathering tan to yellow, "rust-stained", fine-grained to medium-grained, massive, ripple-marked, overlain by gray, fissile shale. Ironstone concretions near top and common in overlying shale (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)........	12	3.6
CLOVERLY FORMATION:		
9. Claystone, variegated gray, yellow, rust-brown, weathers yellow buff to gray, massive to poorly bedded, some ironstone concretions (= part of Himes Member, Cloverly Formation; part of Unit VII of this report)............................	11	3.3
8. Sandstone, buff to light-gray, weathers to dark rust, yellow, fine-grained, well-indurated, massive......................................	1	0.3
7. Claystone, gray with yellow to rust staining, weathers gray at base, variegated red brown in mid-section, and variegated yellow, brown and buff in upper half. Massive non-bedded, forms steep, fluted slopes. Occasional polished pebbles.		

	Thickness	
	(ft)	(m)
Fossil bone level 12 feet (3.6 m) above base (YPM 64-53). (= part of Himes Member, Cloverly Formation; Unit VII of this report)	28	8.5
6. Claystone, variegated red and gray, weathers brick red to purple with yellow limonite staining, silty, poor stratification, fissile in part. Polished pebbles common throughout, but not closely associated with fossil bone. Bone, at 3 feet (0.9 m) below top (YPM 64-61, 65-1) and 2 feet (0.6 m) above base (YPM 64-65). (= part of Himes Member, Cloverly Formation; Unit VII of this report)	18	5.5
5. Siltstone, gray, weathers brown, well-indurated, usually not exposed	1	0.3
4. Claystone, gray, becoming darker near top, to variegated green and red, weathers red brown, yellow to gray, non-bedded, silty. Bone-bearing in lower 4 feet (1.2 m) (YPM 64-57, 64-58, 64-74, 64-75). (= part of Unit VII of this report)	9	2.7
3. Siltstone, dull-gray to red, weathers brown to reddish, poorly stratified, ledge-former	2.5	0.7
2. Sandstone, gray to buff, weathers to tan or brown, fine- to medium-grained, well-indurated, massive (= Unit VI? of this report)	1-2	0.3-0.6
1. Claystone, dark-gray weathering to light-gray. Unstratified, bentonitic, weathering to soft "popcorn" surfaces littered with chalcedony and barite concretions. Fossil bone at several levels in section exposed (YPM 64-54). Base concealed. (= part of Little Sheep Mudstone Member, Cloverly Formation; part of Unit V of this report)	> 21	> 6.4

Concealed.

SECTION 24 - BLUEWATER CREEK

Composite section measured in the exposures south and north of North Fork Bluewater Creek in the immediate vicinity of the point where the Fish Hatchery road crosses Bluewater Creek. The lower part of the section was measured north of this crossing in SE 1/4 Sec. 5 and the upper part of the section was measured southwest of the crossing in NW 1/4 Sec. 8, T. 6 S., R. 24 E., Carbon County, Montana.

		Thickness (ft)	(m)
SYKES MOUNTAIN FORMATION:			
13.	Sandstone, orange and rusty-brown, light-brown and sparkly on fresh surfaces. Thin-bedded and interbedded with black, fissile shale. Fine-grained quartz, well-cemented with limonite and hematite. Some ripple marks. Overlain by fissile, dark shale with thin strata of dark sandstone. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)	17	5.2
CLOVERLY FORMATION:			
12.	Claystone, variegated, predominantly red, red-brown, maroon, purple and violet-gray. Unstratified, breaks into irregular violet-gray and maroon-mottled blocks with some slickensides. Sandy throughout. Few sand lenses. One 6 foot (1.8 m) sandstone wedge 200 yds (183 m) to the south, 20 feet (6.1 m) below top. Polished pebbles or "gastroliths" present, but not abundant. Localities YPM 64-71 and 64-72 are situated near the base of this claystone. (= Himes Member, Cloverly Formation; Unit VII of this report)	91	27.7
11.	Sandstone, tan, yellow to tan on fresh surfaces. Medium-grained, subrounded quartz with some feldspar. Thin-bedded, but with prominent cross-beds. General appearance is very similar to #13 above, but lighter in color and lacking shale interbeds. (= Unit VI of this report)	3	0.9
10.	Claystone, variegated, predominantly dark-gray, light-gray to white, pink. Fresh surfaces generally drab medium- to dark-gray. Unstratified, breaks into small irregular dark-gray chips. Bentonitic in upper part, weathering to light-gray, soft, "popcorn"-covered gentle slopes. Chalcedony and barite concretions abundant, except in upper 15 feet (4.5 m). Calcareous concretions common in lower half. Several 1 to 3 inch (2.5 to 7.5 cm), white limestone strata at the 40 and 48 foot (12 and 14.5 m) levels. A persistent dark-brown, 8 to 12 inch (20 to 30 cm) limestone, dark-gray on fresh surface, at the 78 foot (24 m) level. Irregular dark-brown fragments of this limestone litter all slopes beneath. (= Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	96	29.2

	Thickness	
	(ft)	(m)
9. Conglomerate, dark-gray and brown, very conspicuous massive "rim rock" capping many dip slopes and mesas in the area. Coarse sand and pebbles up to 2 and 3 inches (5 and 7.5 cm), composed chiefly of black, gray, dark-brown and yellow chert, some yellow quartzite and white quartz. Sand lenses have peppery appearance. All fragments well- to subrounded. Large scale cross-beds in sandstone and fine conglomerate facies. (= Pryor Conglomerate; Unit IV of this report)	45	13.7
MORRISON FORMATION:		
8. Claystone, blue-gray and light-gray, calcareous and silty. Unstratified and nonresistant. Poorly exposed, often covered by large blocks fallen from overlying unit. No chalcedony or barite concretions observed. Some thin (6 to 10 inch [15 to 25 cm]) sandstone strata noted, all appear to be discontinuous over short distances, but exposures do not permit verification. (= part of Unit III of this report)	95	29
7. Sandstone, tan, light-gray on fresh surfaces. Medium-grained, but some pebbly lamina locally. Weathers into smooth, rounded, massive blocks. Bedding massive, cross-laminations rare. Prominent ledge-former locally, but not as prominent as unit # 9 above. Grains almost entirely quartz, some light-gray chert. (Tentatively equated with Unit II of this report)	36	11
6. Claystone, variegated, rose-colored in lower half, tan or gray in upper half. Silty and calcareous throughout. Nonresistant and partially concealed. Infrequent satin spar seams, but no chalcedony, barite or calcareous concretions. (=part of Unit I of this report)	88	26.8
5. Sandstone, light-tan both weathered and fresh. Fine-grained, almost a siltstone. Massive bedding, a resistant ledge-former. (Probably equals part of Unit I of this report)	3	0.9
4. Claystone, greenish-gray to very pale-green. Fresh surfaces medium-gray. Unstratified. (= part of Unit I of this report)	27	8.2

	Thickness (ft)	(m)
3. Sandstone, light-tan or buff, fresh surfaces nearly white. Fine-grained, massive and well-indurated, forming prominent, light-colored bluffs	17	5.2
2. Claystone, greenish-yellow, sandy and calcareous. Nonresistant and largely concealed. (May represent upper part of Sundance Formation.)	11	3.3

SUNDANCE FORMATION:

	Thickness (ft)	(m)
1. Sandstone, light-gray to gray-green, coarse to medium-grained. Thin-bedded, locally weathers into thin sheets, but massive at other levels. Glauconitic locally. Gryphaea fragments abundant.	Not measured	

SECTION 25 - PRYOR, MONTANA

Composite section taken at several points along the north side of the Pryor-Edgar road, 4 to 6 miles (6.4 to 9.6 km) west of Pryor, Montana, SW 1/4 Sec. 29, N 1/2 Sec. 33 and SE 1/4 Sec. 34, T.4 S., R.25 E., Big Horn County, Montana. Except for the upper claystone, the conglomerate, and some of the massive sandstones, exposures in this area are very poor. This incomplete section is included to tie together the Carbon County sections and those to the east along Beauvais Creek.

SYKES MOUNTAIN FORMATION:

	Thickness (ft)	(m)
12. Sandstone, rusty-brown to tan, fresh surfaces tan. Medium- to fine-grained quartz in well-rounded grains. Thin-bedded sand strata with very thin interbeds of dark shale. Forms cap-rock on plateaus. Overlying strata concealed. (= Greybull sandstone?; Sykes Mountain Formation in part?; Unit VIII of this report)	8	2.4

CLOVERLY FORMATION:

	Thickness (ft)	(m)
11. Claystone, variegated, red-brown, maroon, and bluish-purple. Fresh surfaces blue-gray with some green and maroon mottling. Sandy at top and near base of exposure. Forms steep, brightly colored slopes. Polished stones or "gastroliths" common. Base concealed. (= Himes Member, Cloverly Formation; Unit VII of this report)	>72	>21.9

	Thickness	
	(ft)	(m)
10. Concealed interval	41±	12.5±
9. Sandstone, tan to dark-brown, fresh surfaces light-brown. Medium-grained, quartz. Massive with pronounced cross-beds. Concealed at most sites. Base concealed. (= Unit VI? of this report).	>15	>4.5
8. Concealed interval	35±	10.6±
7. Conglomerate, dark-gray and brown. Lower 25 feet (7.6 m) coarse gray sandstone, massive and strongly cross-laminated, with occasional 0.25 to 0.5 inch (0.6 to 1.2 cm) pebbles of dark chert. Upper 30 feet (9 m), conglomeratic with well-rounded pebbles up to 2 inches (5 cm) of black, gray and brown chert, and yellow and gray quartzite. Massive, well-cemented and resistant. (= Pryor Conglomerate; Unit IV of this report)	55	16.7
MORRISON FORMATION:		
6. Concealed interval	42±	12.8±
5. Sandstone, buff to light-brown, fresh surfaces buff and nearly white. Medium- to coarse-grained quartz with some white or light-gray chert of well-rounded grains. Massive with some cross-stratification. (= Unit II? of this report)	12	3.6
4. Concealed interval	31±	9.4±
3. Sandstone, tan to brown, light-gray on fresh surfaces. Sparkly. Medium-grained, rounded quartz. Well-indurated and resistant. Some thin strata near middle. (= part of Unit I? of this report).	15	4.5
2. Concealed interval. (Probably includes lowest part of continental sequence and perhaps part of upper strata of Sundance Formation.)	110	33.5
SUNDANCE? FORMATION:		
1. Sandstone, nearly white to pale-green. Medium-grained quartz and glauconite, calcareous. Interbedded thin and massive strata. No invertebrate fossils observed	Not measured	

Concealed.

SECTION 26 - PUSH CREEK

Section measured in south-facing scarp, "around the corner" 0.25 mile (0.4 km) east of Thor Lande's ranch house on Push Creek, NE 1/4 Sec. 22, T. 5 S., R. 28 E., Big Horn County, Montana.

	Thickness (ft)	(m)
SYKES MOUNTAIN FORMATION:		
9. Sandstone, light-gray, weathers tan to light brown, medium-grained, rounded quartz grains, thin-bedded, with cross-laminations and ripple marks. Interbedded with thin dark shale layers at irregular intervals, ironstone concretions at top. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)........................	18	5.5
CLOVERLY FORMATION:		
8. Claystone, variegated dark-gray, weathers to purplish gray or light gray, yellow and purple. Mottling, silty, massive to poorly stratified (= part of Himes Member, Cloverly Formation; part of Unit VII of this report)..................	10	3
7. Claystone, dark-gray, weathers to vivid red and maroon. Polished pebbles common, poorly stratified to massive. Breaks into irregular slickensided blocks. (= part of Himes Member, Cloverly Formation; Unit VII of this report)...............	15	4.5
6. Sandstone, gray weathers pale green, medium- to coarse-grained, sub-angular quartz and feldspar. Massive, well-developed parallel stratification, well-cemented, forms resistant gray-green ledge..	2	0.6
5. Claystone, variegated, red, maroon, and green. Massive and resistant, silty throughout, frequent thin green sand or silt layers, polished pebbles common. Forms steep, fluted slopes. Localities YPM 64-39, 64-40 and 64-41 are situated in this claystone (= part of Himes Member, Cloverly Formation; Unit VII of this report).................	16	4.9
4. Sandstone, gray, weathers to yellow or purple gray, coarse, grit- to pea-sized pebbles in upper 5 feet (1.5 m), poorly-cemented, but caps prominent bench at base of variegated claystone. Quartz,		

	Thickness	
	(ft)	(m)
feldspar, and chert predominant. Locality YPM 64-40 produced bone from the upper 8 to 10 inches (20 to 25 cm) of this sandstone as well as the lower foot (30 cm) of the overlying claystone. (= Unit VI of this report)	9	2.7
3. Claystone, gray, weathers to variegated red brown, purple, yellow and green. Nonbedded or massive, some silt. Polished pebbles and chalcedony concretions absent. (= part of Little Sheep Mudstone Member?, Cloverly Formation; part of Unit V? of this report)	11	3.3
2. Concealed interval	20±	6.1±
1. Claystone, variegated, predominantly blue-gray, purple-gray and pink. Bentonitic, weathering to soft, "popcorn" surface. Fresh rock medium- to dark-gray, breaking into irregular chips. Chalcedony concretions common locally. Base concealed. (= part of Little Sheep Mudstone Member, Cloverly Formation; Unit V of this report)	>46	>14

Concealed.

SECTION 27 - BUSTER CREEK

Section measured at southwestern extremity of the large bench between Buster Creek and Horse Coulee and immediately south of Beauvais Creek, 0.25 mile (0.4 km) east of Buster Creek and 1.5 miles (2.4 km) southwest of Cashen Ranch. SE 1/4 Sec. 32, T. 4 S., R. 29 E., Big Horn County, Montana. This is the only locality within the Crow Indian Reservation west of the Bighorn River at which the entire nonmarine sequence is continuously exposed.

SYKES MOUNTAIN FORMATION:

12. Sandstone, dark-brown and rusty-orange, fresh surfaces tan. Thin-bedded, with thin interbeds of dark fissile shale at irregular intervals. Medium-grained, well-rounded quartz, with limonite and hematite staining. Ironstone concretions common in upper 5 to 6 feet (1.5 to 1.8 m). Ripple marks prevalent on nearly all sandstone bedding planes.

		Thickness (ft)	(m)
	Forms rim-rock of nearly all benches along Beauvais Creek in this Township. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report)......................	14	4.2
CLOVERLY FORMATION:			
11.	Claystone, variegated, gray, red-orange, violet and red-brown. Fresh surfaces gray with maroon and green mottling, breaks into irregular blocks with slickensides. Massive or unstratified. (= part of Himes Member, Cloverly Formation; part of Unit VII of this report).................	35	10.6
10.	Sandstone, fine to medium-grained, pink or light-gray. Very dense and extremely well-indurated quartzite. Very resistant.....................	1- 3	0.3- 0.9
9.	Claystone, variegated, chiefly gray and red-brown to orange. Fresh surfaces, gray with purple and maroon mottling. Massive or unstratified except for occasional discontinuous 3 to 8 inch (7.5 to 20 cm) sandstone lenses. Polished pebbles or "gastroliths" common. Localities YPM 64-16, 64-17, 64-18, 64-19, 64-31 and 64-33 all lie within this claystone. (= part of Himes Member, Cloverly Formation; part of Unit VII of this report)	45	13.7
8.	Sandstone, tan on fresh surfaces, weathers brown, fine- to medium-grained quartz and feldspar in rounded grains. Thin to massive, parallel stratification, cross-laminations common in massive strata. Thickness variable over short distance. Localities AM 32-6 and 32-7 are situated in this channel sandstone. (= Unit VI of this report)....	8	2.4
7.	Claystone, variegated, gray to purple here, red-brown to east. Fresh rock neutral-gray. Sandy locally. Poorly stratified. (= part of Little Sheep Mudstone Member, Cloverly Formation; part of Unit V of this report).........................	11	3.3
6.	Sandstone, brown, tan on fresh surfaces. Medium- to fine-grained, chiefly quartz with some feldspar and light-colored chert. Massive and thin-bedded. Some cross laminations	4.5	1.3

	Thickness (ft)	(m)
5. Claystone, drab-gray to blue-gray, varies from nearly white to medium gray. Fresh surfaces medium gray. Bentonitic, weathers to soft "popcorn" surfaces. Massive or unstratified. Chalcedony concretions present, locally abundant. Barite concretions rare. Two localities - (OU 40-10 and 40-11) probably occur within this claystone, but their precise levels are not known. (= part of Little Sheep Mudstone Member, Cloverly Formation; part of Unit V of this report)........................	19	5.8
MORRISON FORMATION:		
4. Limestone, white to light-gray, weathers chalky white. Medium-sized crystals. Dense and massive, very resistant. Apparently persistent......	1	0.3
3. Claystone, variegated, orange-red, purple and drab-dark-gray. Fresh surfaces dark-gray and violet. Calcareous and locally silty. Unstratified, fresh rock breaks into irregular waxy chips and blocks. Often forms steep, smooth, brightly-colored slopes. Chalcedony and barite concretions apparently lacking, but pink satin spar was noted rarely. (Quite dissimilar from usual claystone facies of "Morrison" part of sequence. May represent a lower portion of Unit V, but absence of chalcedony concretions suggests otherwise.).........................	46	14
2. Concealed interval. (Nearest underlying exposures approximately 200 yards [180 m] to south. Dip at the two exposures the same [10° N 20° W]; dip projection established that a maximum of 20 feet [6 m] of section is concealed. Slope between exposures irregular, but averages close to 10°, presumed to be a dip slope maintained by underlying sandstone. If correct, the concealed section probably represents less than the 20 foot [6 m] interval mentioned above.).....................	20±	6.1±
SUNDANCE FORMATION:		
1. Sandstone, gray to nearly white, light-greenish-gray on fresh surfaces. Medium-grained, quartz with calcareous cement. Varies from thin to massive bedding. Glauconite not evident at most exposures, but Gryphaea shells and fragments are..	Not measured	
Concealed.		

SECTION 28 - CASHEN RANCH, BEAUVAIS CREEK

Section measured on the southeast slope of "Cashen Pocket", 0.5 mile (0.8 km) southeast of the Cashen ranch house, on the south side of Beauvais Creek, SE 1/4 Sec. 28, T. 4 S., R. 29 E., Big Horn County, Montana. A number of localities discovered by Barnum Brown (AM 31-3, 31-4, 31-5, 31-6, 31-7) are in the immediate vicinity.

	Thickness	
SYKES MOUNTAIN FORMATION:	(ft)	(m)
6. Sandstone, tan, weathers rusty brown, medium-grained quartz, well-rounded. Thin-bedded with occasional massive units up to 2 and 3 feet (0.6 to 0.9 m) thick. Thin interbeds of black, fissile shale weathering rusty yellow, hematite lamina. Ripple marks prominent, occasional cross-beds in massive beds. (= Greybull sandstone; Sykes Mountain Formation in part; Unit VIII of this report).	18	5.5
CLOVERLY FORMATION:		
5. Claystone, variegated, dark-purple, pink, gray-green, red-brown, maroon and brick-red, often with greenish mottling and occasional medium- to dark-gray bands. Various color bands grade into each other, but quite persistent laterally. Fresh rock usually fractures into irregular blocks with some slickensides, but occasionally breaks into fine, irregular chips. Parallel stratification lacking or very obscure on fresh surfaces. Silty or sandy locally, but not persistently. Polished pebbles, common locally, but usually rare. Generally this unit forms steepest slopes below capping sandstone (Unit VIII), but locally, slump blocks form lower-angle slopes. Sites AM 31-5 and YPM 64-3 are situated near base of unit. (= Himes Member, Cloverly Formation?; Unit VII of this report)..	70	21.3
4. Sandstone, olive-green, weathering to gray green to dull red brown. Medium- to coarse-grained quartz and feldspar. Friable locally, elsewhere well-indurated and blocky. Massive, with prominent cross-beds. Discontinuous. A single site (AM 31-6) is situated near base of sandstone. (= Unit VI of this report)......................	12	3.6

	Thickness	
	(ft)	(m)
3. Claystone, dark-gray, weathering to light gray or pale lavender gray and nearly white. Poorly stratified or massive, fresh rock fractures into small, irregular chips with waxy surfaces. Bentonitic, weathers to soft "popcorn" surfaces. Chalcedony concretions present, but not abundant. Occasional satin spar seams. At least one, discontinuous massive, 0.5 to 1 foot (15 to 30 cm) thick gray limestone bed. American Museum localities: 31-3, 31-4, 31-7, 31-8 and 32-8, and Yale locality YPM 64-13 are situated in the upper 30 feet (9 m) of this unit. (= Little Sheep Mudstone Member, Cloverly Formation?; Unit V of this report).......	43	13.1
2. Sandstone, gray to gray-brown, tan on fresh surfaces. Medium-grained quartz in well-rounded grains. Massive, parallel-stratification. Discontinuous..................................	3	0.9
MORRISON FORMATION:		
1. Claystone, light-gray, dark-gray and gray-green on fresh surfaces. Calcareous. Unstratified. Exposures generally poor, and form low-angle slopes in this region. Forms base of "pocket". No chalcedony found *in situ*, but concretions may be present. Base concealed.[1] (= Unit V or III? of this report)................................	> 27	> 8.2

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[1] (Fragments of *Gryphaea* shells were found at several places in the lowest part of this depression, but none were found in place, nor were any exposures seen here that resembled the Sundance Formation as exposed in this part of the Reservation. *Gryphaea* fragments were found only at low points in the "pocket" and were not significantly abraded. In view of the nature of the terraine and the location of the nearest Sundance outcrops, it appears likely that the Sundance Formation lies very close to (if not actually exposed at) the surface. Thus the entire nonmarine section here may be only about 150 feet (45 m) thick. At Section No. 27, it is 173 to 193 feet (52 to 59 m) thick.

APPENDIX B

REGISTER OF CLOVERLY FORMATION FOSSIL VERTEBRATE LOCALITIES

The following locality register lists more than one hundred sites at which fossil vertebrate remains have been collected from the upper part of the Cloverly-Morrison sequence -- that part which Moberly (1960) included in his redefined Cloverly Formation. These include sites discovered by expeditions from the American Museum of Natural History (1903, 1904, 1931, 1932, 1933, 1938 and 1955), Oklahoma University (1940), Princeton University (1948, 1949), none of which have previously been reported, and recent expeditions by Yale University (1962, 1963, 1964, 1965 and 1966). To the best of my knowledge this register includes all of the collection sites from the upper (Cloverly) part of this sequence. Most of the listed sites are located precisely here, as well as on the numerous locality maps, but some localities of early expeditions, particularly those of 1933 and 1938, could not be relocated by us and are only approximately located in this register. Many other sites discovered by the Yale expeditions are not included here because they were never excavated and no collections were made from them, higher priority having been assigned to other more promising sites. The unexploited sites usually featured only unidentifiable bone fragments on the surface, but future excavation of any of these might well prove profitable. Time simply was not available to open exploratory excavations at each site discovered.

LOCALITY MAP LEGEND

⊙ Y.P.M. 62-10	Yale fossil vertebrate locality
X Sec. 20	Location of measured section
— — —	Trails or unimproved roads
━━━	Graded or paved roads
┈┈┈	Intermittant drainage
〰	Perennial streams
▭	Outcrop area of units VI, VII (Cloverly Formation)
┬┬┬	Scarps

AMERICAN MUSEUM OF NATURAL HISTORY LOCALITIES

AM 03-26[1,2] T.4 S., R.29 E., Big Horn County, Montana.
Horizon: unknown.
Specimen collected: Crocodilia (AMNH 5852).

AM 03-28[2] T.4 S., R.29 E., Big Horn County, Montana.
Horizon: unknown.
Specimen collected: *Sauropelta edwardsi*? (AMNH 5853).

AM 03-29[2] T.4 S., R.29 E., Big Horn County, Montana.
Horizon: unknown.
Specimen collected: *Tenontosaurus tilletti* (AMNH 5854).

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[1] The first two digits of locality designations refer to the year of discovery, the following digit(s) to the particular site as recorded in field records.

[2] These sites cannot be located precisely. Barnum Brown stated that they were 25 miles (40 km) southeast of Pryor, Montana near Cashen ranch, which in all probability places them along Beauvais Creek.

AM	03-30[3]	T.4 S., R.29 E., Big Horn County, Montana. Horizon: unknown, but probably Unit III. Specimen collected: Sauropoda (AMNH 5855).
AM	04-9[4]	T.4 S., R.29 E., Big Horn County, Montana. Horizon: unknown. Specimen collected: *Sauropelta edwardsi*? (AMNH 5833).
AM	04-10[5]	T.4 S., R.29 E., Big Horn County, Montana. Horizon: unknown, but probably Unit VII. Specimen collected: *Naomichelys speciosa* (AMNH 6136).
AM	31-3	"Cashen Pocket". NW 1/4 Sec. 33, T.4 S., R.29 E., 0.25 mile (0.4 km) SSE of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit V, 8 feet (2.4 m) below Unit VI. Specimen collected: *Tenontosaurus tilletti* (AMNH 3010).
AM	31-4	"Cashen Pocket". NE 1/4 Sec. 33, T.4 S., R.29 E., 0.5 mile (0.8 km) SE of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit V. Specimen collected: *Tenontosaurus tilletti* (AMNH 3013).
AM	31-5	"Cashen Pocket". NW 1/4 Sec. 33, T.4 S., R.29 E., 0.25 mile (0.4 km) SSE of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VII, 10 to 20 feet (3 to 6 m) above Unit VI. Specimen collected: *Tenontosaurus tilletti* (AMNH 3020).
AM	31-6	"Cashen Pocket". NW 1/4 Sec. 33, T.4 S., R.29 E., 0.25 mile (0.4 km) SE of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VI, or possibly uppermost part of Unit V. Specimen collected: *Tenontosaurus tilletti* (AMNH 3012).
AM	31-7	"Cashen Pocket". NW 1/4 Sec. 33, T.4 S., R.29 E., 0.5 mile (0.8 km) SE of the Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit V, 23 feet (7 m) below Unit VI. Specimens collected: *Deinonychus antirrhopus* (AMNH 3015); *Tenontosaurus tilletti* (AMNH 3014).
AM	31-8	NW 1/4 Sec. 33, T.4 S., R.29 E., 0.25 mile (0.4 km) south of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit V, approximately 20 feet (6 m) below Unit VI. Specimen collected: *Tenontosaurus tilletti* (AMNH 3011).

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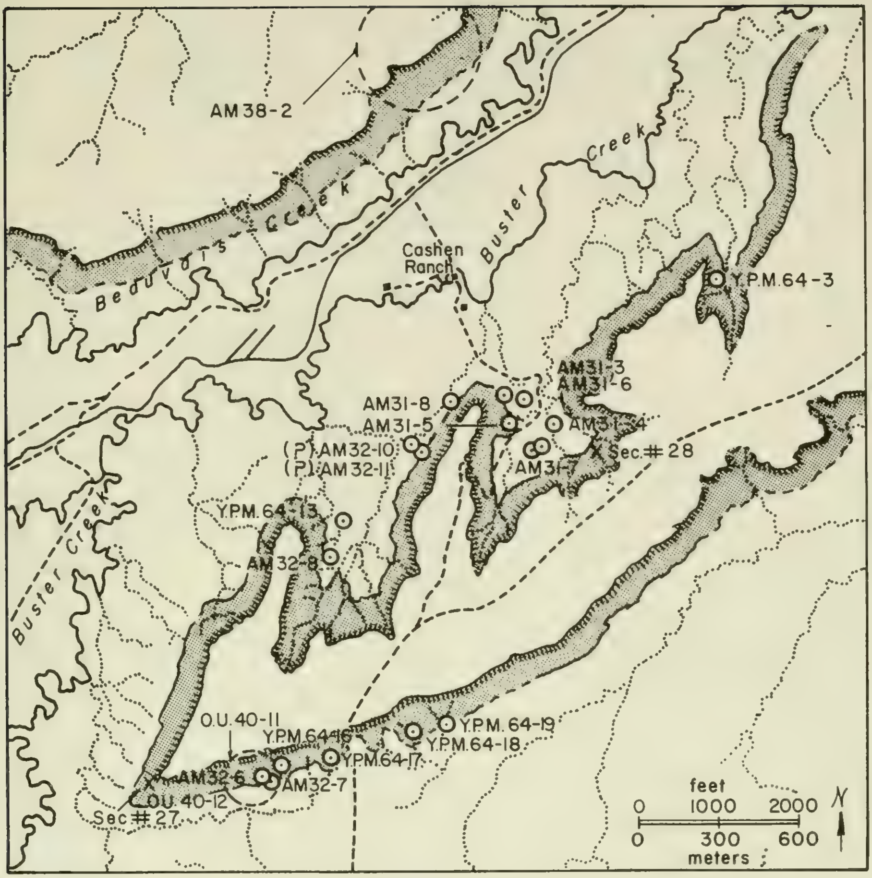
[3] This locality was located by Brown on Horse Coulée, 30 miles (48 km) east of Pryor, Montana. No more precise location is possible now.

[4] Barnum Brown recorded this locality as 50 miles (80 km) south of Billings, Montana on Beauvais Creek, which means it probably lies in Section 22 or 23, between the entrances of Buster Creek and Horse Coulée into Beauvais Creek.

[5] The only information available now places this site at 25 miles (40 km) east of Pryor, Montana, which suggests the Cashen ranch area (similar descriptions were given for other sites discovered later that have been pinpointed in the Cashen ranch area), probably along Beauvais Creek.


AM38-2
Beauvais Creek
Buster Creek
Cashen Ranch
Y.P.M.64-3
AM31-3
AM31-6
AM31-8
AM31-5
AM31-4
Sec.# 28
(P) AM32-10
(P) AM32-11
AM31-7
Y.P.M.64-13
AM32-8
Buster Creek
O.U.40-11
Y.P.M.64-16
Y.P.M.64-19
Y.P.M.64-18
Y.P.M.64-17
AM32-6
AM32-7
O.U.40-12
Sec.# 27
feet
0 1000 2000
0 300 600
meters
N

LOCALITY MAP U

See regional map (Fig.2) in pocket for location

AM 31-9[6] SE 1/4 Sec. 16, T.4 S., R.26 E., 3.5 miles (5.6 km) north of Pryor, Yellowstone County, Montana. See Locality Map P.
Horizon: Unit V?
Specimen collected: Sauropelta edwardsi (AMNH 3016).

AM 31-10[6] SW 1/4 Sec. 16, T.4 S., R.26 E., 0.25 mile (0.4 km) west of AM31-9, Yellowstone County, Montana. See Locality Map P.
Horizon: Unit VII.
Specimen collected: Tenontosaurus tilletti (AMNH 3017).

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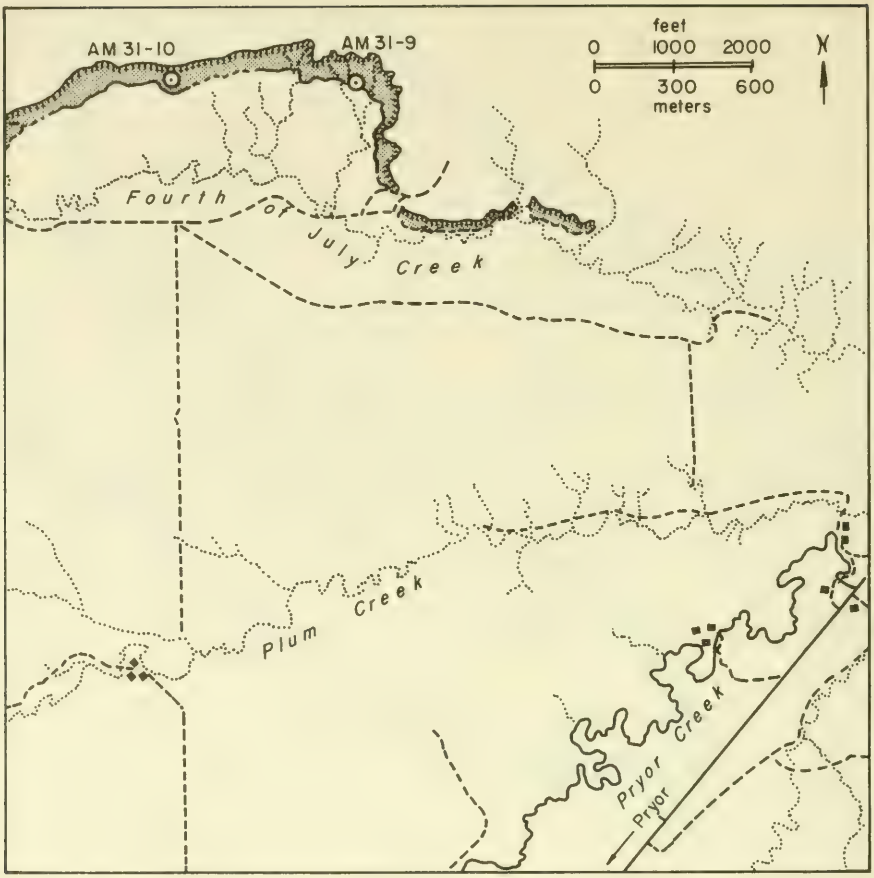
[6] Sites AM 31-9 and 31-10 were relocated with the help of Mr. Roy Marsh of Pryor, Montana, who worked for Barnum Brown at these excavations.


AM 31-10
AM 31-9
feet
0 1000 2000
0 300 600
meters
Fourth of July Creek
Plum Creek
Pryor Creek
Pryor

LOCALITY MAP P

AM 32-2[7] SW 1/4 Sec. 8, T.5 S., R.30 E., 6 miles (9.6 km) SE of Cashen ranch house, on Mott Creek, Big Horn County, Montana. See Locality Map X.
Horizon: unknown.
Specimen collected: Tenontosaurus tilletti (AMNH 3031).

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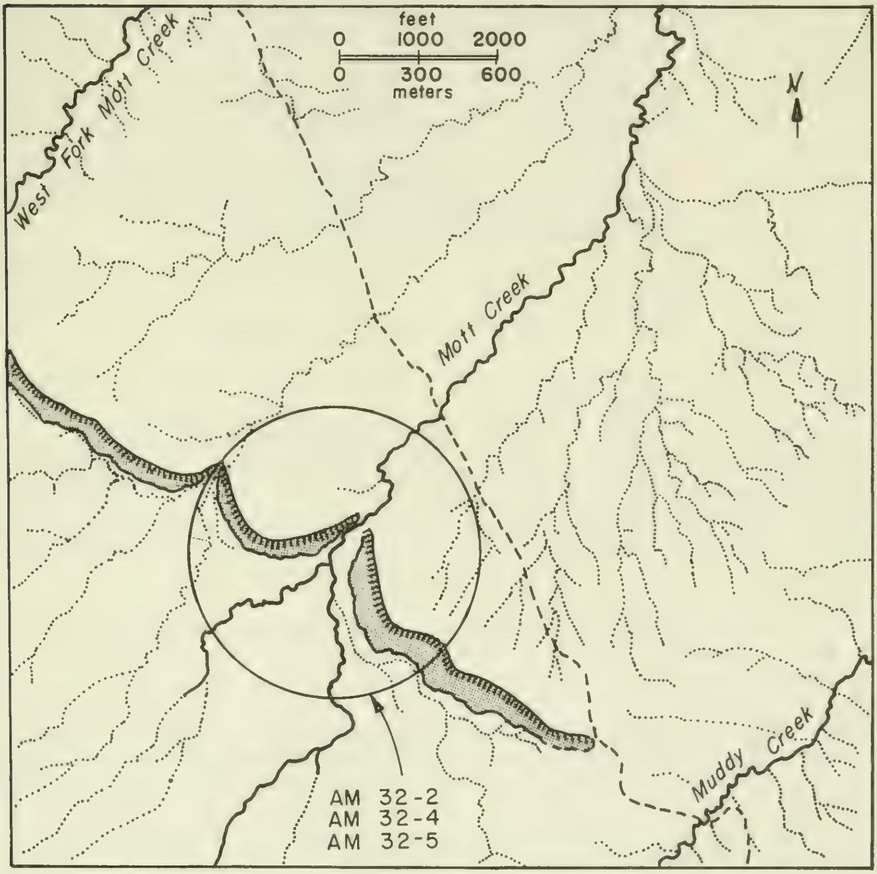
[7] Barnum Brown described the location of sites 32-2, 4, and 5 as "9 miles (14.4 km) east of Cashen's ranch on Mott Creek". However, there are no exposures of the Cloverly Formation more than 2 miles to the east of Cashen's ranch. From Horse Coulée the outcrop trends southeasterly and is crossed by Mott Creek 6 miles (9.6 km) southeast of Cashen's ranch. No where else along the course of Mott Creek does the Cloverly Formation crop out. Therefore, I have provisionally placed localities AM 32-2, 32-4, and 32-5 within a 2000 foot (610 m) radius of this crossing.

AM 32-3[8] NE 1/4 Sec. 20, T.5 S., R.28 E., Approximately 1.5 miles (2.4 km) west of Thor K. Lande ranch, on Push Creek, Big Horn County, Montana. See Locality Map Q.
Horizon: Unit V, VI or VII.
Specimens collected: Sauropelta edwardsi (AMNH 3032).

AM 32-4[7] SW 1/4 Sec. 8, T.5 S., R.30 E., 6 miles (9.6 km) SE of Cashen ranch house, on Mott Creek, Big Horn County, Montana. See Locality Map X.
Horizon: unknown.
Specimen collected: Sauropelta edwardsi (AMNH 3033).

AM 32-5[7] SW 1/4 Sec. 8, T.5 S., R.30 E., 6 miles (9.6 km) SE of Cashen ranch house, on Mott Creek, Big Horn County, Montana. See Locality Map X.
Horizon: unknown.
Specimens collected: Deinonychus antirrhopus (AMNH uncatalogued); Tenontosaurus tilletti (AMNH 3034).



LOCALITY MAP X

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[8] Brown's field records describe this locality simply as "10 miles (16 km) SW of Cashen's ranch, Montana", but a field photograph places the "nodosaur" (AMNH 3232) and "camptosaur" (AMNH 3062?) in the region specified here and in Locality Map Q.

AM	32-6	SE 1/4 Sec. 32, T.4 S., R.29 E., 1.25 mile (2 km) SSW of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VI, 3 feet (0.9 m) below Unit VII. Specimen collected: Sauropelta edwardsi (AMNH 3035).
AM	32-7	SE 1/4 Sec. 32, T. 4 S., R.29 E., 1.25 mile (2 km) SSW of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VI, 8 feet (2.4 m) below Unit VII. Specimen collected: Sauropelta edwardsi (AMNH 3036).
AM	32-8	NE 1/4 Sec. 32, T.4 S., R.29 E., 0.75 mile (1.2 km) SSW of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit V, 5 to 15 feet (1.5 to 4.5 m) below Unit VI. Specimen collected: Deinonychus antirrhopus (AMNH 3037).
AM AM	32-10? 32-11?	These sites have been placed on Locality Map U, on information recorded by Barnum Brown on an oblique areal photograph (see Plate 6:B). It is not known what, if anything, was collected at these sites. All known specimens collected by Brown in the Crow Indian Reservation are accounted for and known to have come from other sites. These sites appear to be in Unit V.
AM	33-1[9]	SW 1/4 Sec. 26, T.7 N., R.16 E., Wheatland County, Montana. Horizon: Unit VII?, approximately 60 feet (18 m) below base of Unit VIII. Specimens collected: Tenontosaurus tilletti (AMNH 3040); Deinonychus antirrhopus (teeth associated with AMNH 3041); Microvenator celer (AMNH 3041).
AM	33-2	Sec. 26, 27, 34, or 35, T.7 N., R.16 E., Wheatland County, Montana. Horizon: Unit VII? Specimen collected: Sauropoda (AMNH 3042).
AM	33-3	Sec. 26, 27, 34 or 35, T.7 N., R.16 E., Wheatland County, Montana. Horizon: Unit VII?. Specimen collected: Tenontosaurus tilletti (AMNH 3043).
AM	33-4[10]	Sec. 34, T.7 N.?, R.16 E., Wheatland County, Montana. Horizon: unknown. Specimen collected: Tenontosaurus tilletti (AMNH 3044).
AM	33-5[10]	Sec. 34, T.7 N.?, R.16 E., Wheatland County, Montana. Horizon: unknown. Specimen collected: Tenontosaurus tilletti (AMNH 3045).

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[9] Brown's field records place the following six localities at Middle Dome, 12 miles (19.2 km) southeast of Harlowton, Montana. Except for Locality 33-1, no record of the precise location exists. A photograph (Plate 7:B) from Barnum Brown's files pinpoints Locality AM 33-1 on the north rim of Middle Dome approximately 0.5 mile (0.8 km) from the north entrance into the Middle Dome basin. Inquiry and exploration of the Middle Dome exposures failed to determine other locations.

[10] These two localities were placed by Barnum Brown in Sec. 34, T. 4 N., R.16 E. There are no Cloverly exposures within 15 miles (24 km) of this location and it is probable that Brown's notation was intended to read T.7 N. instead of T.4 N., where Cloverly exposures crop out along the south flank of Middle Dome.

AM	33-6	Sec. 26; 27, 34 or 35, T.7 N., R.16 E., Wheatland County, Montana. Horizon: unknown. Specimen collected: *Sauropelta*? (AMNH 3046).
AM	33-8[11]	?Sec. 16, or 17, T.7 S., R.24 E., 6 miles? (9.6 km) SE of Bridger, Carbon County, Montana. Horizon: unknown. Specimen collected: *Tenontosaurus tilletti* (AMNH 3050).
AM	38-1[12]	?NE 1/4 Sec. 20, T.5 S., R.28 E., approximately 8 miles (12.8 km) SW of Cashen ranch house and 1.5 mile (2.4 km) west of Thor K. Lande ranch on Push Creek, Big Horn County, Montana. See Locality Map Q. Horizon: Unit V, VI or VII. Specimen collected: *Tenontosaurus tilletti* (AMNH 3062).
AM	38-2	NW 1/4 Sec. 28, T.4 S., R. 29 E., 0.5 mile (0.8 km) north of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: unknown. Specimen collected: *Sauropelta*? (AMNH 3064).
AM	38-3[13]	T.4 S., R.29 E., Big Horn County, Montana. Horizon: unknown. Specimen collected: *Tenontosaurus tilletti* (AMNH 3061).
AM	38-4[14]	T.7 N., R.16 E., Wheatland County, Montana. Horizon: unknown. Specimen collected: *Tenontosaurus tilletti* (AMNH 3063).

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[11] The precise location of this site is not known. Barnum Brown placed it "11 miles (17.6 km) east of Bridger, Montana, near Red Dome." No Cloverly exposures could be found in the area 11 miles east of Bridger, but extensive exposures do occur approximately 6 miles (9.6 km) SE of Bridger and in the immediate vicinity of Red Dome. Consequently, it is presumed that locality AM 33-8 was in this area, probably close to localities YPM 64-54, 64-57, 64-58, 64-74, 64-75. See Locality Map L.

[12] No precise location can be given for this site because R. T. Bird recorded its location simply as 10 miles (16 km) SW of Cashen's ranch. However, the Cloverly formation is completely covered west of the ridge end 1.5 miles (2.4 km) west of Push Creek, making it unlikely that the site was situated further to the west. Moreover, a handwritten notation by Brown on the back of a photograph indicates that this locality was at the western end of the outcrop in the area cited here and shown in Locality Map Q, in the vicinity of AM 32-3. No detailed field records are available to establish this, though.

[13] A precise location cannot be given for this locality. R. T. Bird described it as "2 miles (3.2 km) East of Cashen's ranch", which would place it somewhere along the east side of Horse Coulée near YPM 64-23 if distances and bearings were recorded accurately.

[14] Field records of R. T. Bird indicate this locality was in Middle Dome, 12 miles (19.2 km) southeast of Harlowton, Montana. This would place it somewhere in the southern part of T.7 N., R.16 E., Wheatland County, Montana.

AM 55-1?[15] T.4 S., R.29 E., Big Horn County, Montana.
Horizon: unknown.
Specimen collected: ?*Ornithomimus* sp. (AMNH uncatalogued).

AM 55-2?[15] T.4 S., R.29 E., Big Horn County, Montana.
Horizon: unknown.
Specimen collected: ?*Ornithomimus* sp. (AMNH uncatalogued).

UNIVERSITY OF OKLAHOMA LOCALITIES

OU 40-11[16] SE 1/4 Sec. 32, T.4 S., R.29 E., 1.25 miles (2 km) SSW of Cashen ranch house, 400 yards (366 m) west of road, Big Horn County, Montana. See Locality Map U.
Horizon: Unit V.
Specimen collected: *Tenontosaurus tilletti* (OU 11).

OU 40-12[16] SE 1/4 Sec. 32, T.4 S., R.29 E., 1.25 miles (2 km) SSW of Cashen ranch house near OU 40-11, Big Horn County, Montana. See Locality Map U.
Horizon: Unit V.
Specimen collected: *Tenontosaurus tilletti* (OU 12).

PRINCETON UNIVERSITY LOCALITIES

PU 48-1[17] T.6 N., R.15 E., or T.6 N., R.16 E., Wheatland County, Montana.
Horizon: unknown.
Specimen collected: *Tenontosaurus tilletti* (PU 16338).

PU 49-1[18] NW 1/4 Sec. 34, T.58 N., R.95 W., 1.75 miles (2.8 km) SW of Tillett Fish Hatchery, Big Horn County, Wyoming. See Locality Map H.
Horizon: Unit V, 35 to 40 feet (10.6 to 12.2 m) below Unit VI.
Specimens collected: *Ceratodus frazieri* (YPM 5276); *Tenontosaurus tilletti* (PU 16514).

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[15] No precise location can be given for these sites. Brown simply recorded it as "Beauvais Creek", which, on the basis of known distribution of Cloverly exposures, would place them somewhere between the junctions of Buster Creek and Horse Coulée with Beauvais Creek in the general vicinity of the Cashen ranch.

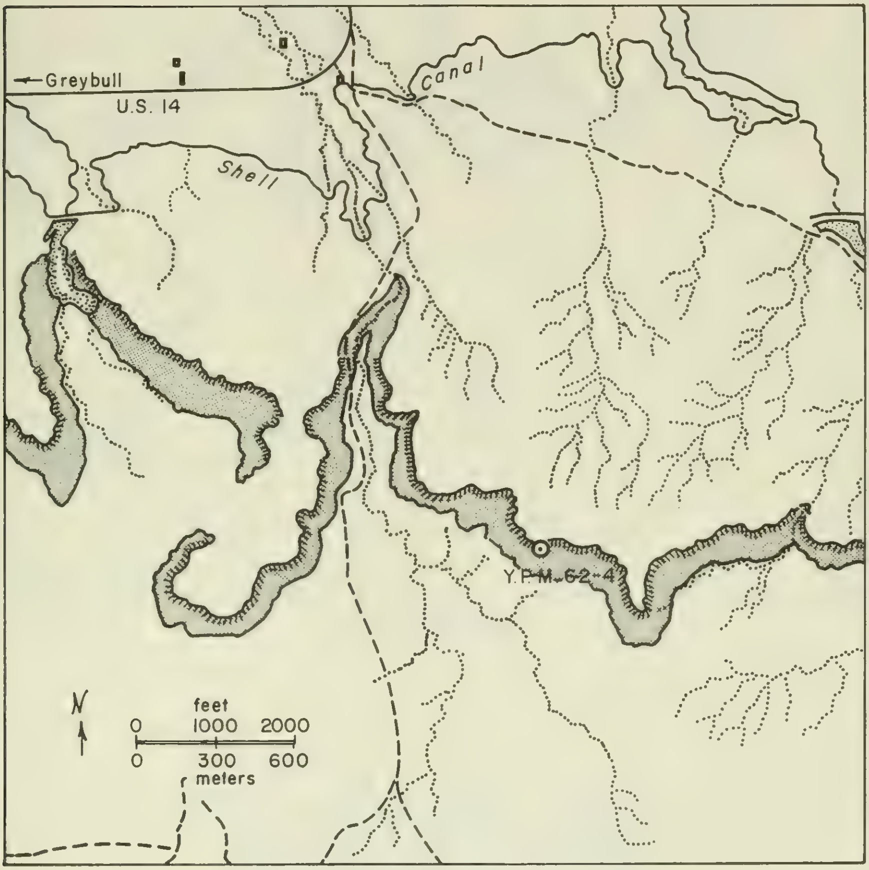
[16] I am indebted to Dr. Wann Langston of the Texas Memorial Museum for providing the location of these sites.

[17] No precise location can be given for this specimen (Pu 16338). Al Silberling indicated it was collected from the Cloverly Formation southeast of Harlowton, Montana. The only extensive exposures known to the author in that area are in Middle Dome, T.7 N., R.16 E., Wheatland County, Montana.

[18] Mr. Lloyd Tillett of Lovell, Wyoming directed me to the site at which Al Silberling collected the Princeton specimen from Crooked Creek in 1950.

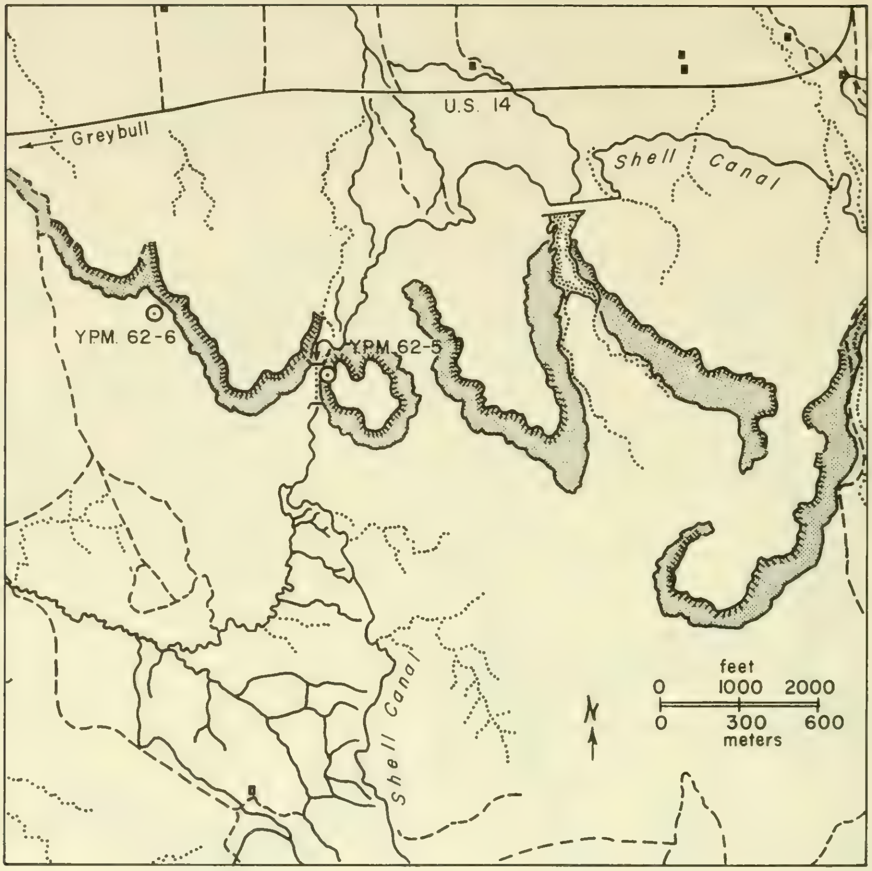
PEABODY MUSEUM, YALE UNIVERSITY, LOCALITIES

YPM 62-4 NW 1/4 Sec. 12, T.52 N., R.92 W., 4 miles (6.4 km) WSW of Shell, Big Horn County, Wyoming. See Locality Map D.
Horizon: Unit VII, 7 feet (2.1 m) above Unit VI.
Specimen collected: Tenontosaurus? (YPM 4882).


Greybull
U.S. 14
Canal
Shell
YPM 62-4
N
feet
0
1000
2000
0
300
600
meters

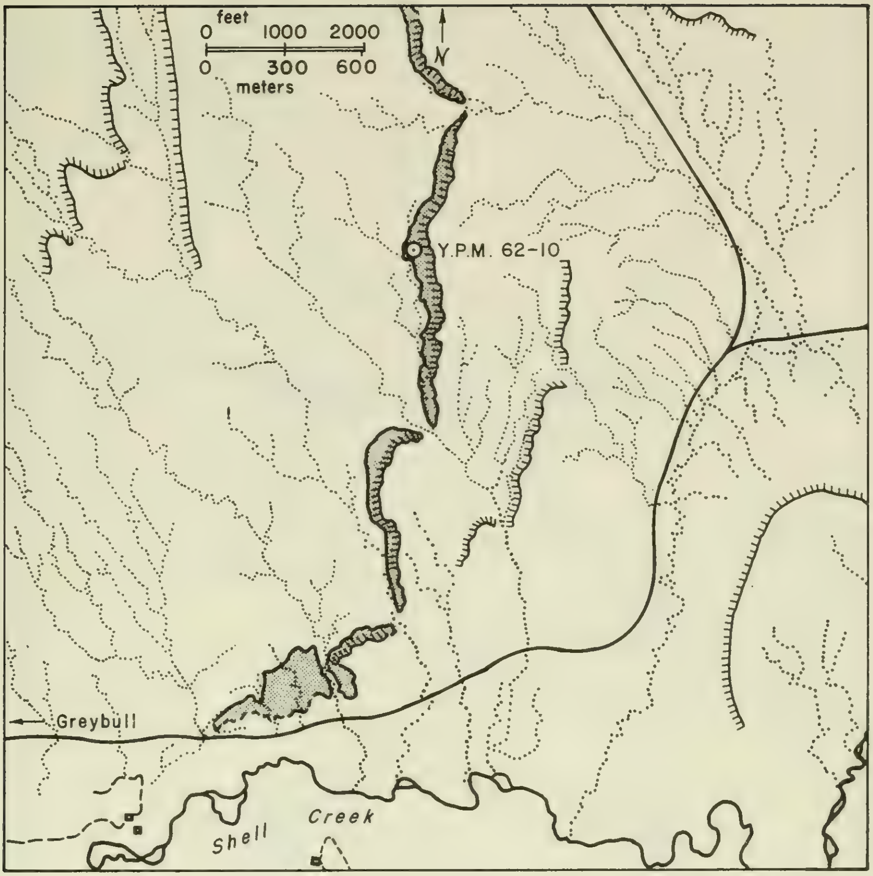
LOCALITY MAP D

YPM 62-5 SE 1/4 Sec. 3, T.52 N., R.92 W., 5.5 miles (8.8 km) WSW of Shell, Big Horn County, Wyoming. See Locality Map E.
Horizon: Unit VII, 15 feet (4.5 m) above Unit VI.
Specimens collected: Crocodilia? (YPM 4883, 4884).


U.S. 14
Greybull
Shell Canal
YPM 62-6
YPM 62-5
Shell Canal
feet
0 1000 2000
0 300 600
meters
N

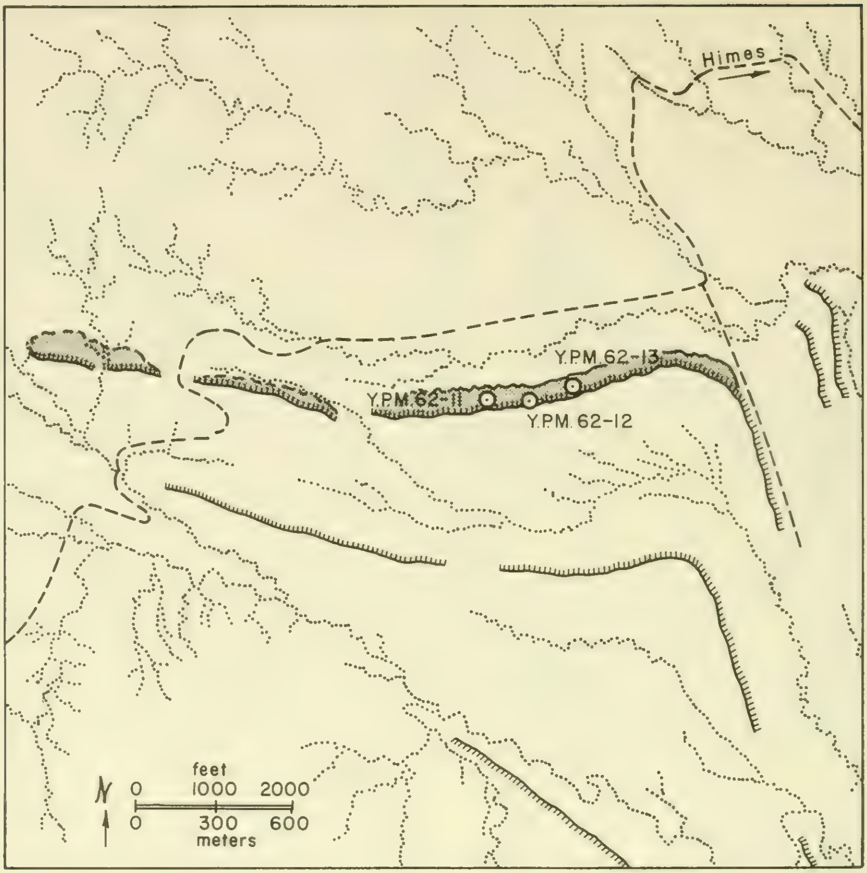
LOCALITY MAP E

YPM 62-6	SW 1/4 Sec. 3, T.52 N., R.92 W., 6 miles (9.6 km) WSW of Shell, Big Horn County, Wyoming. See Locality Map E. Horizon: Unit V, 30 feet (9 m) below Unit VI. Specimens collected: Deinonychus antirrhopus (YPM 4886, 4887; Theropoda, Megalosauridae (YPM 4885).
YPM 62-10	SE 1/4 Sec. 26, T.53 N., R.93 W., Big Horn County, Wyoming, 0.8 mile (1.2 km) WNW of junction of Bentonite Company road and road to Kane, 4 miles (6.4 km) NE of Greybull, Wyoming. See Locality Map F. Horizon: Unit VII, 5 to 8 feet (1.5 to 2.4 m) above Unit VI. Specimens collected: Sauropelta edwardsi (YPM 5511, 5512, 5513).



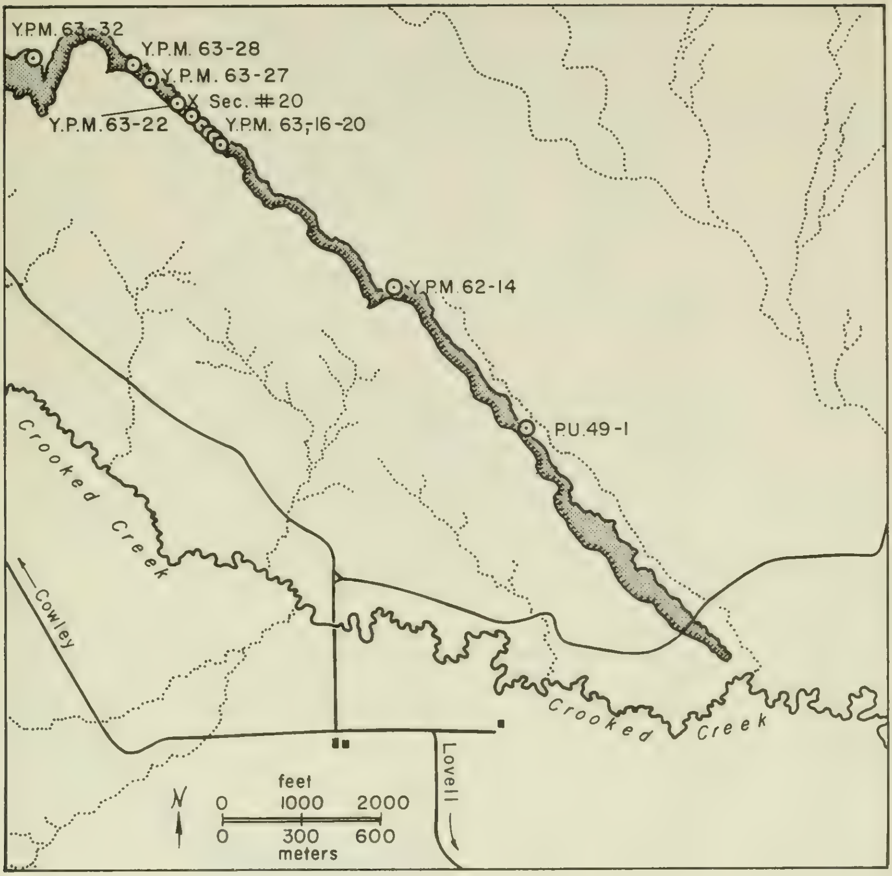
LOCALITY MAP F

YPM 62-11	NE 1/4 Sec. 1, T.54 N., R.95 W., 2.5 miles (4 km) WSW of Himes, Big Horn County, Wyoming. See Locality Map G. Horizon: Unit VII, 2 to 3 feet (0.6 to 0.9 m) below Unit VIII. Specimens collected: Glyptops? pervicax (YPM 4889, 4891); Crocodilian tooth (YPM 4890); Sauropelta? (YPM 4892).
YPM 62-12	NE 1/4 Sec. 1, T.54 N., R.95 W., 2.5 miles (4 km) WSW of Himes, Big Horn County, Wyoming. See Locality Map G. Horizon: Unit VII, 2 to 3 feet (0.6 to 0.9 m) below Unit VIII. Specimen collected: Glyptops? (YPM 4893).
YPM 62-13	NE 1/4 Sec. 1, T. 54 N., R.95 W., 2.5 miles (4 km) WSW of Himes, Big Horn County, Wyoming. See Locality Map G. Horizon: Unit VII, 2 to 3 feet (0.6 to 0.9 m) below Unit VIII. Specimens collected: Glyptops pervicax? (YPM 4894, 5282); Crocodilia (YPM 4895).



LOCALITY MAP G

YPM 62-14	NW 1/4 SE 1/4 Sec. 28, T. 58 N., R.95 W., 1.75 miles (3 km) WSW of Tillett Fish Hatchery, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit V, 20 feet (6 m) below Unit VI. Specimens collected: Sauropoda (YPM 5455); Deinonychus antirrhopus (YPM 5275); Tenontosaurus tilletti (BB #1).
YPM 63-16	NW 1/4 Sec. 28, T.58 N., R.95 W., 20 yards (18 m) SE of YPM 63-17, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit VI, 1 to 3 feet (0.3 to 0.9 m) below Unit VII. Specimens collected: Crocodilia (YPM 5444, 5401); Ornithomimus sp. YPM 5284); Theropoda (YPM 5369); Sauropoda (YPM 5452); Sauropelta edwardsi (YPM 5296, 5297, 5298, 5402, 5405, 5408, 5409); Sauropelta? (YPM 5406).
YPM 63-17	NW 1/4 Sec. 28, T.58 N., R.95 W., 20 yards (18 m) NW of YPM 63-16, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit VII, 5 to 8 feet (1.5 to 2.4 m) above Unit VI. Specimens collected: Sauropelta edwardsi (YPM 4896, 4905).


Y.P.M. 63-32
Y.P.M. 63-28
Y.P.M. 63-27
X Sec. #20
Y.P.M. 63-22
Y.P.M. 63-16-20
Y.P.M. 62-14
P.U. 49-1
Crooked Creek
Cowley
Crooked Creek
Lovell
N
feet
0 1000 2000
0 300 600
meters

LOCALITY MAP H

YPM 63-18 NW 1/4 Sec. 28, T.58 N., R.95 W., 20 yards (18 m) NW of YPM 63-17, Big Horn County, Wyoming. See Locality Map H.
Horizon: Unit VII, 2 to 8 feet (0.6 to 2.4 m) above Unit VI.
Specimens collected: Crocodilia (YPM 5343, 5345, 5346, 5348, 5357, 5358, 5439, 5172, 5128, 5129); *Deinonychus antirrhopus* (YPM 5379, 5371); *Ornithomimus* sp. (YPM 5174); Theropoda (YPM 5378); Sauropoda (YPM 5449, 5451, 5347, 5375, 5419, 5152, 5116); Sauropoda? (YPM 5294); *Sauropelta edwardsi* (YPM 5111-5115, 5118-5122, 5124, 5127, 5130, 5131, 5133, 5134, 5137, 5138, 5141, 5149, 5154-5159, 5161, 5163-5169, 5173, 5175-5179, 5181-5183, 5192, 5200, 5295, 5301-5305, 5307, 5309-5315, 5317, 5320-5327, 5333-5341, 5391, 5393, 5486-5498, 5528); *Sauropelta*? (YPM 5125, 5136, 5140, 5150, 5193, 5306, 5308, 5316, 5318, 5319, 5328, 5330-5332, 5390, 5394, 5395, 5485, 5515).

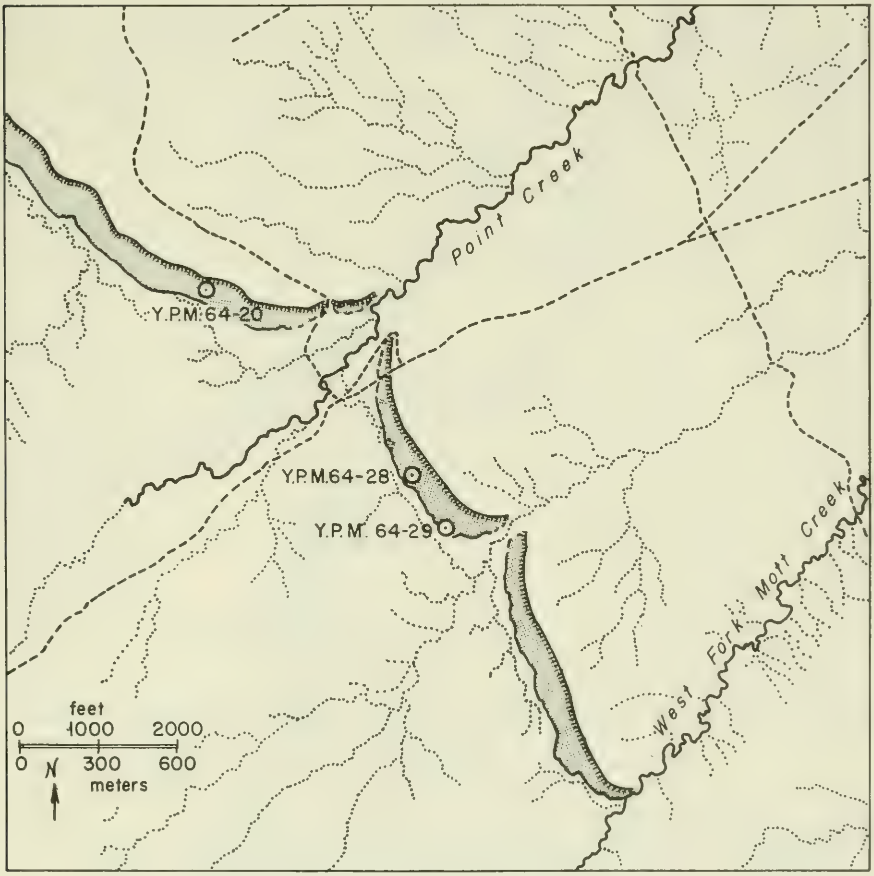
YPM 63-19 NW 1/4 Sec. 28, T.58 N., R.95 W., 30 yards (27 m) NW of YPM 63-18, Big Horn County, Wyoming. See Locality Map H.
Horizon: Unit VII, 0 to 8 feet (0 to 2.4 m) above Unit VI.
Specimens collected: *Naomichelys speciosa* (YPM 5385, 5432, 5433, 5434); *Deinonychus* (YPM 5271, 5441, 5274, 5356, 5376); Crocodilia (YPM 5344, 5353, 5354, 5355, 5359, 5361, 5362, 5363,

	5364, 5372, 5381, 5342, 5440, 5447, 5445, 5110, 5384); Theropoda (YPM 5377, 5408, 5538); *Microvenator celer*? (YPM 5366); Sauropoda (YPM 5103, 5104, 5107, 5147, 5151, 5450, 5349, 5360, 5365, 5374); *Tenontosaurus tilletti* (YPM 5099); *Sauropelta edwardsi* (YPM 5069-5072, 5074, 5075, 5079-5084, 5086, 5094, 5095, 5098, 5101, 5102, 5105, 5106, 5108, 5109, 5142-5146, 5148, 5149, 5184-5189, 5191, 5194, 5196, 5198, 5350-5352, 5367, 5368, 5389, 5442, 5448, 5499-5503, 5505-5510, 5516, 5525-5527, 5529); *Sauropelta*? (YPM 5076-5078, 5085, 5150, 5190, 5504).
YPM 63-20	NW 1/4 Sec. 28, T.58 N., R.95 W., 75 yards (69 m) NW of YPM 63-19, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit VII, 5 to 8 feet (1.5 to 2.4 m) above Unit VI. Specimens collected: *Sauropelta edwardsi* (YPM 5511, 5512, 5513).
YPM 63-22	NW 1/4 Sec. 28, T.58 N., R.95 W., 210 yards (192 m) NW of YPM 63-20, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit V, 2 feet (0.6 m) below Unit VI. Specimen collected: *Sauropelta*? (YPM 4897).
YPM 63-27	NW 1/4 Sec. 28, T.58 N., R.95 W., 225 yards (199 m) NW of YPM 63-22, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit VII, 3 feet (0.9 m) above Unit VI. Specimen collected: Testudinidae? (YPM 4900).
YPM 63-28	NW 1/4 Sec. 28, T.58 N., R.95 W., 15 yards (13.7 m) NW of YPM 63-27, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit VII, 1 foot (0.3 m) above Unit VI. Specimen collected: Testudinata, family *incertae sedis* (YPM 4903).
YPM 63-32	NE 1/4 Sec. 29, T.58 N., R.95 W., 500 yards (455 m) due west — "over the scarp" — of YPM 63-28, Big Horn County, Wyoming. See Locality Map H. Horizon: Unit VI, 1 to 3 feet (0.3 to 0.9 m) below Unit VII. Specimen collected: *Tenontosaurus tilletti* (YPM 4904).
YPM 64-3	SE 1/4 Sec. 28, T.4 S., R.29 E., 0.75 mile (1.2 km) east of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VII, 4 to 6 feet (1.2 to 1.8 m) above Unit VI. Specimens collected: Theropoda (YPM 5397); *Ornithomimus*? (YPM 5286); Sauropoda (YPM 5453); Crocodilia (YPM 5398).
YPM 64-13	NE 1/4 Sec. 32, T.4 S., R.29 E., 0.6 mile (0.9 km) WSW of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit V, 18 feet (5.5 m) below Unit VI. Specimen collected: *Tenontosaurus* sp. (YPM 5410).
YPM 64-16	SE 1/4 Sec. 32, T.4 S., R.29 E., 1.25 mile (2 km) SSW of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VII, 4 feet (1.2 m) above Unit VI. Specimen collected: *Tenontosaurus*? (YPM 5299).
YPM 64-17	SW 1/4 Sec. 33, T.4 S., R.29 E., 1.25 mile (2 km) SSW of Cashen ranch house, Big Horn County, Montana. See Locality Map U. Horizon: Unit VII, 11 feet (3.3 m) above Unit VI. Specimen collected: *Tenontosaurus tilletti* (YPM 5535).

YPM 64-18 SW 1/4 Sec. 33, T.4 S., R.29 E., 350 yards (320 m) east of YPM 64-17, 1 mile (1.6 km) south of Cashen ranch house, Big Horn County, Montana. See Localty Map U.
Horizon: Unit VII, 45 to 50 feet (13.7 to 15 m) below Unit VIII.
Specimens collected: *Naomichelys speciosa* (YPM 5437); Crocodilia (YPM 5412, 5438, 5443, 5414, 5415); *Deinonychus antirrhopus* (YPM 5420); Sauropoda (YPM 5449); *Tenontosaurus* sp. (YPM 5411, 5413, 5416).

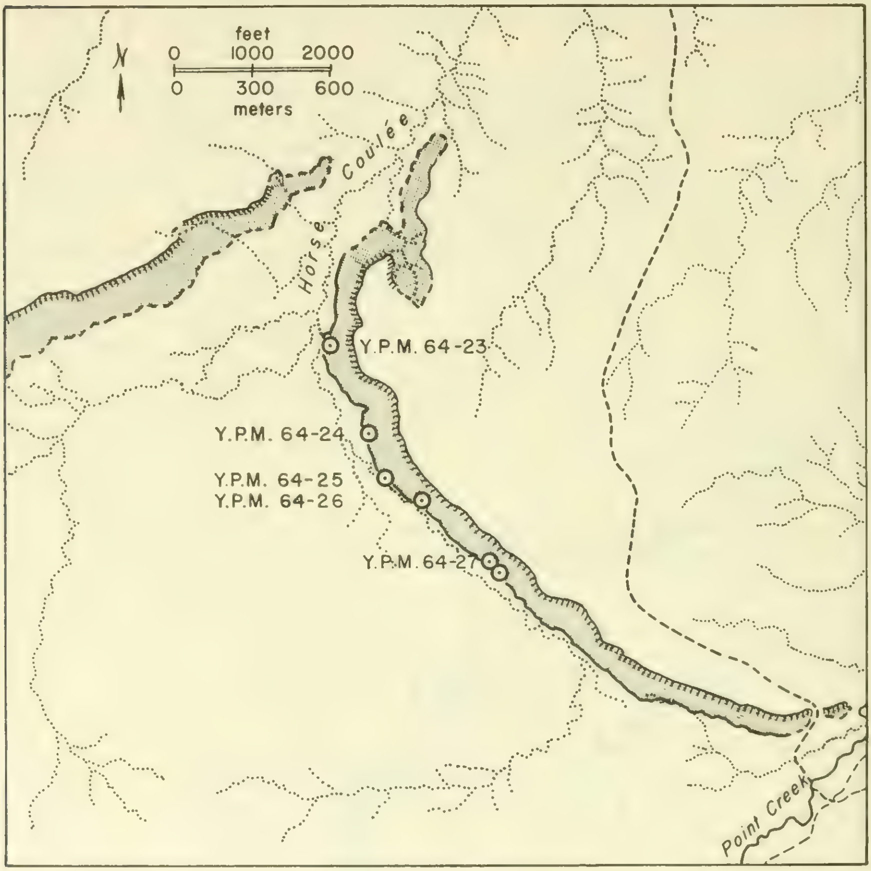
YPM 64-19 SW 1/4 Sec. 33, T.4 S., R.29 E., 150 yards (137 m) east of YPM 64-18, 1 mile (1.6 km) south of Cashen ranch house, Big Horn County, Montana. See Locality Map U.
Horizon: Unit VII, 45 to 50 feet (13.7 to 15 m) below Unit VIII.
Specimens collected: *Tenontosaurus* sp. (YPM 5421, 5424).

YPM 64-20 SW 1/4 Sec. 36, T.4 S., R.29 E., 3 miles (4.8 km) ESE of Cashen ranch house, 700 yards (640 m) NW of Point Creek, Big Horn County, Montana. See Locality Map W.
Horizon: Unit VII, 7 feet (2.1 m) above Unit VI.
Specimens collected: *Tenontosaurus* sp. (YPM 5422, 5426); *Sauropelta edwardsi* (YPM 5511, 5512, 5513).



LOCALITY MAP W

YPM 64-23	SW 1/4 Sec. 26, T.4 S., R.29 E., 2 miles (3.2 km) east of Cashen ranch house on Horse Coulée, Big Horn County, Montana. See Locality Map V. Horizon: Unit VI, 2 feet (0.6 m) below Unit VII. Specimens collected: Crocodilia (YPM 5425); *Tenontosaurus* sp. YPM 5428); *Sauropelta edwardsi* (YPM 5300, 5522).
YPM 64-24	NW 1/4 Sec. 35, T.4 S., R.29 E., 300 yards (274 m) south of YPM 64-23, 2 miles (3.2 km) east of Cashen ranch house, Big Horn County, Montana. See Locality Map V. Horizon: Unit VII, 8 feet (2.4 m) above Unit VI. Specimen collected: *Sauropelta* ? (YPM 5536).



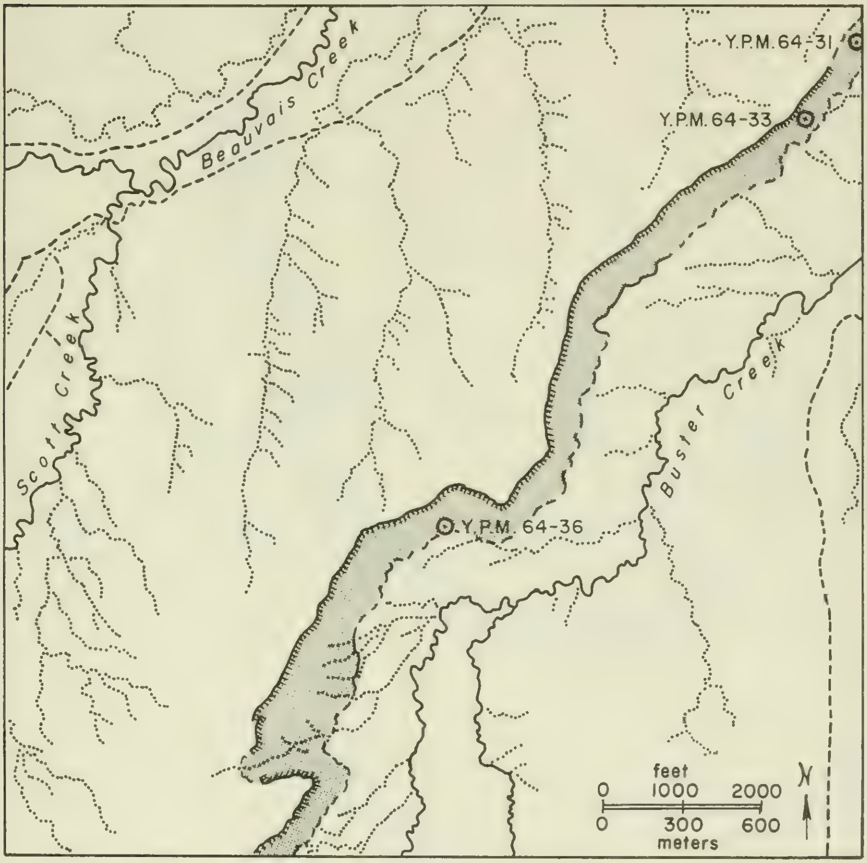
LOCALITY MAP V

YPM 64-25	NW 1/4 Sec. 35, T.4 S., R.29 E., 200 yards (183 m) south of YPM 64-24, Big Horn County, Montana. See Locality Map V. Horizon: Unit VII, approximately 17 feet (5 m) above Unit VI. Specimen collected: *Tenontosaurus*? (YPM 5534).
YPM 64-26	NW 1/4 Sec. 35, T.4 S., R.29 E., 160 yards (146 m) SE of YPM 64-25, Big Horn County, Montana. See Locality Map V. Horizon: Unit VII, approximately 28 feet (8.5 m) above Unit VI. Specimen collected: *Tenontosaurus tilletti* (YPM 5459).

YPM 64-27 SE 1/4 Sec. 35, T.4 S., R.29 E., 300 yards (275 m) SE of YPM 64-26, Big Horn County, Montana. See Locality Map V.
Horizon: Unit VII, 10 feet (3 m) above Unit VI.
Specimens collected: *Deinonychus antirrhopus* (YPM 5283); *Tenontosaurus tilletti* (YPM 5195, 5417).

YPM 64-28 NE 1/4 Sec. 1, T.5 S., R.29 E., 500 yards (457 m) SE of Point Creek, 3.75 miles (6 km) SE of Cashen ranch house, Big Horn County, Montana. See Locality Map W.
Horizon: Unit VII.
Specimen collected: *Tenontosaurus*? (YPM 5533).

YPM 64-29 NE 1/4 Sec. 1, T.5 S., R.29 E., 300 yards (274 m) SE of YPM 64-28, Big Horn County, Montana. See Locality Map W.
Horizon: Unit VII.
Specimen collected: *Sauropelta edwardsi* (YPM 5517).


Beauvais Creek
Y.P.M. 64-31
Y.P.M. 64-33
Scott Creek
Buster Creek
Y.P.M. 64-36
feet
0 1000 2000
0 300 600
meters
N

LOCALITY MAP T

YPM 64-31 NE 1/4 Sec. 6, T.5 S., R.29 E., 2.25 miles (3.6 km) SW of Cashen ranch house, Big Horn County, Montana. See Locality Map T.
Horizon: Unit VII, approximately 42 feet (12.8 m) above Unit VI.
Specimens collected: *Sauropelta edwardsi* (YPM 5531); Dipnoi? (YPM 5537).

YPM 64-33

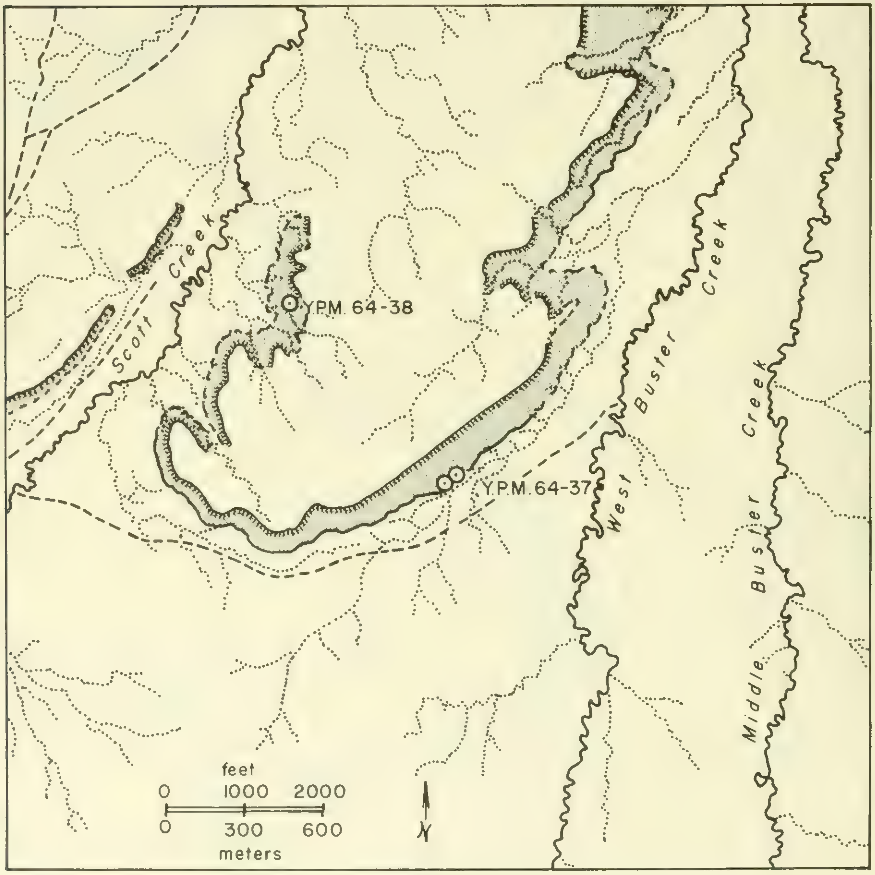
SE 1/4 Sec. 6, T.5 S., R.29 E., 300 yards (275 m) SW of YPM 64-31, Big Horn County, Montana. See Locality Map T.
Horizon: Unit VII, 40 to 45 feet (12 to 13.5 m) above Unit VI.
Specimens collected: *Deinonychus antirrhopus* (YPM 5281, 5288).

YPM 64-36

SE 1/4 Sec. 12, T.5 S., R.28 E., 3.75 miles (6 km) SW of Cashen ranch house, 400 yards (366 m) NW of the junction of West Buster and Middle Buster Creeks, Big Horn County, Montana. See Locality Map T.
Horizon: Unit VII, 1 foot (0.3 m) above Unit VI.
Specimen collected: *Tenontosaurus tilletti* (YPM 5460).

YPM 64-37

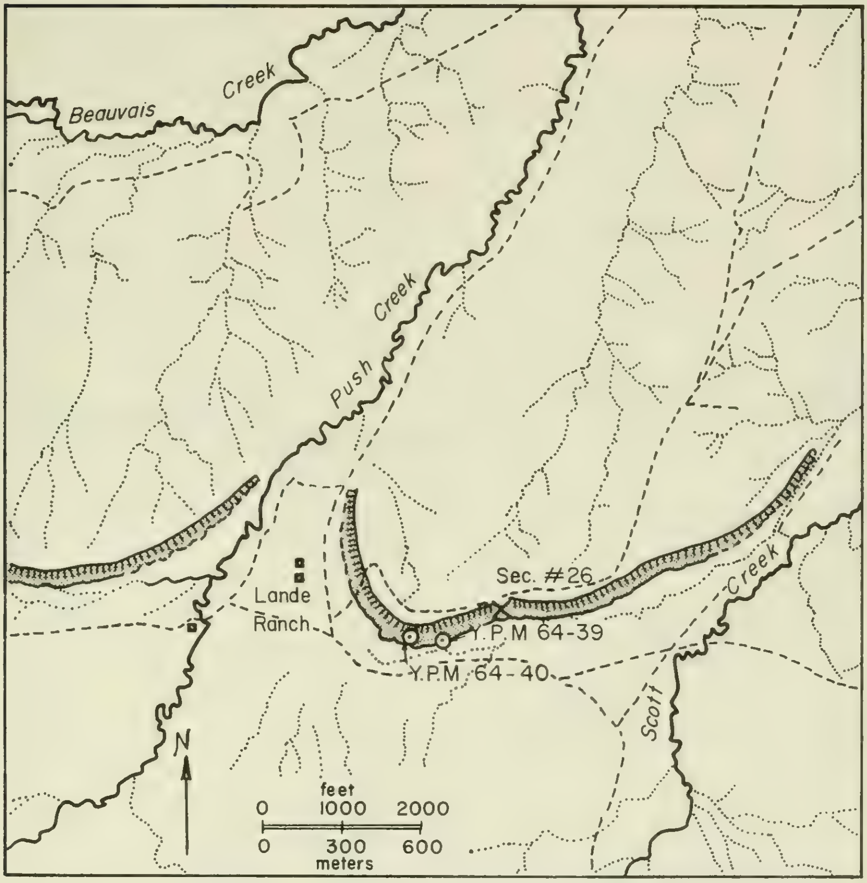
NW 1/4 Sec. 24, T.5 S., R.28 E., 5.5 miles (8.8 km) SW of Cashen ranch house, 600 yards (550 m) west of West Buster Creek, Big Horn County, Montana. See Locality Map S.
Horizon: Unit VII, 14 feet (4.2 m) above Unit VI.
Specimens collected: *Tenontosaurus tilletti* (YPM 5456, 5457, 5483).


Scott Creek
YPM 64-38
YPM 64-37
West Buster Creek
Middle Buster Creek
feet
0 1000 2000
0 300 600
meters
N

LOCALITY MAP S

YPM 64-38 SE 1/4 Sec. 14, T.5 S., R.28 E., 1100 yards (0.9 km) NW of YPM 64-37 on opposite side of mesa, Big Horn County, Montana. See Locality Map S.
Horizon: Unit V?
Specimen collected: Tenontosaurus tilletti (YPM 5476).

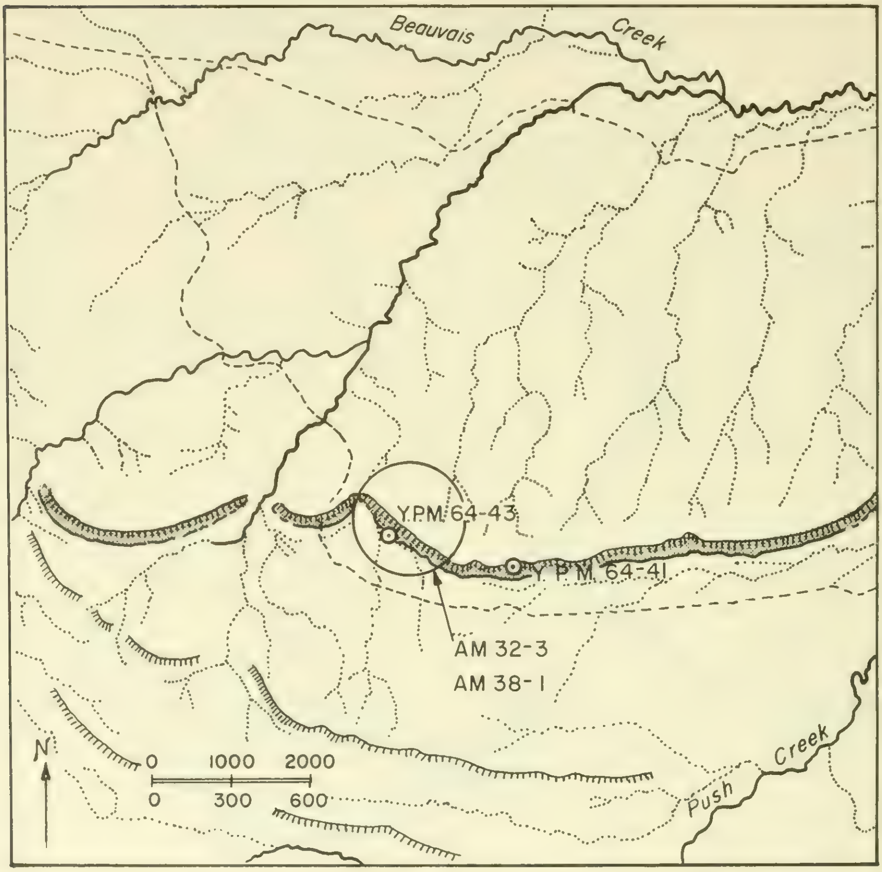
YPM 64-39 NE 1/4 Sec. 22, T.5 S., R.28 E., 700 yards (640 m) east of Thor Lande ranch, on Push Creek, Big Horn County, Montana. See Locality Map R.
Horizon: Unit VII, 16 feet (4.8 m) above Unit VI.
Specimens collected: Sauropoda (YPM 5454); Tenontosaurus sp. (YPM 5482); Naomichelys speciosa (YPM 5518).


Beauvais
Creek
Push
Creek
Lande
Ranch
Sec. #26
Y.P.M 64-39
Y.P.M. 64-40
Scott
Creek
N
feet
0
1000
2000
0
300
600
meters

LOCALITY MAP R

YPM 64-40 NW 1/4 Sec. 22, T.5 S., R.28 E., 500 yards (450 m) east of Thor Lande ranch on Push Creek, Big Horn County, Montana. See Locality Map R.
Horizon: Unit VII, 12 feet (3.6 m) above Unit VI.
Specimen collected: Osteichthyes (Amioidei?) (YPM 5519).

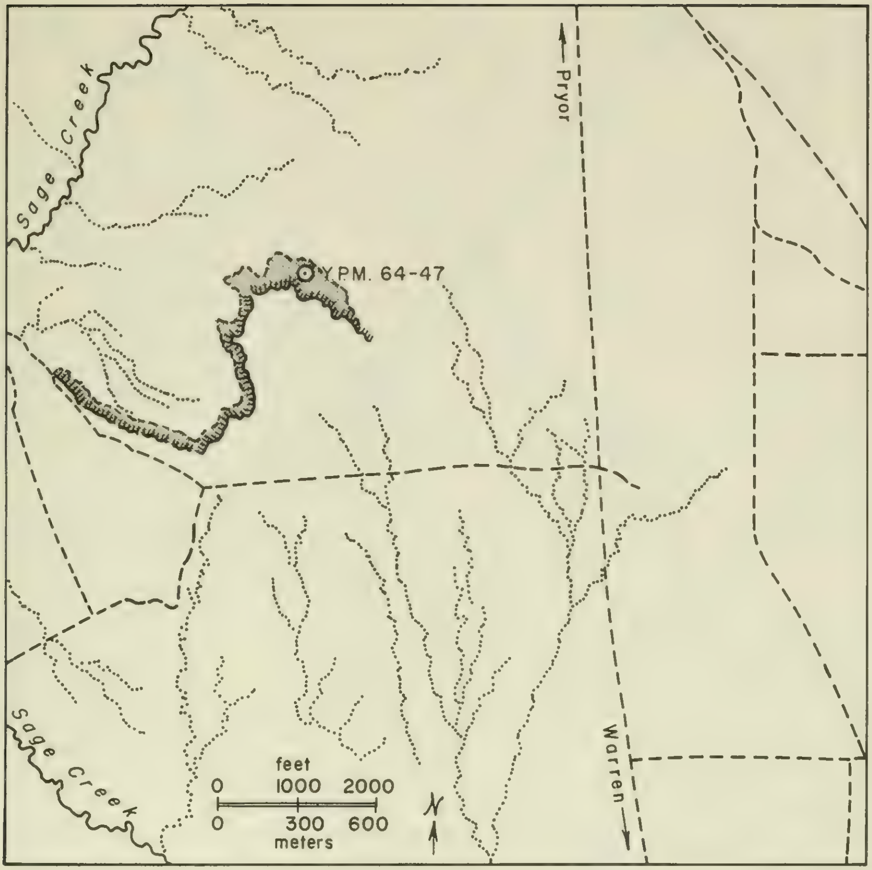
YPM 64-41 NW 1/4 Sec. 21, T.5 S., R.28 E., 1 mile (1.6 km) west of Thor Lande ranch on Push Creek, Big Horn County, Montana. See Locality Map Q.
Horizon: Unit VII, 8 feet (2.4 m) above Unit VI.
Specimens collected: Deinonychus antirrhopus (YPM 5272, 5273); Tenontosaurus tilletti (YPM 5458).



LOCALITY MAP Q

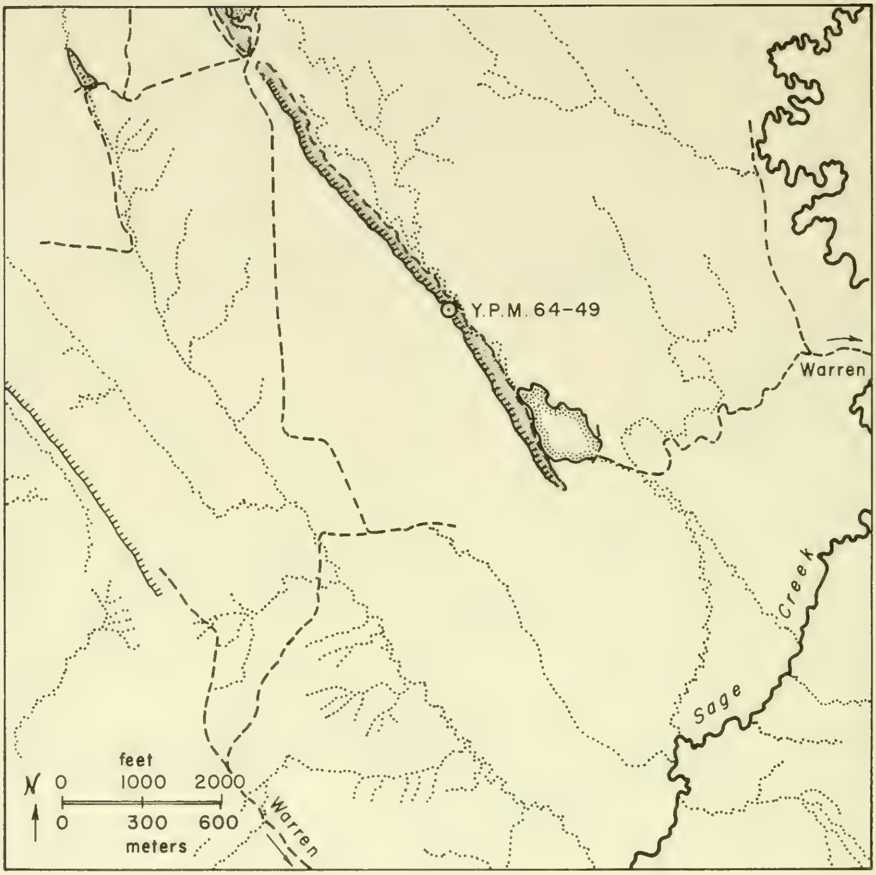
YPM 64-43 NE 1/4 Sec. 20, T.5 S., R.28 E., 650 yards (595 m) west of YPM 64-41, Big Horn County, Montana. See Locality Map Q.
Horizon: Unit VII, 3 feet (0.9 m) above Unit VI.
Specimens collected: Tenontosaurus tilletti (YPM 5464, 5477).

YPM 64-47 NE 1/4 Sec. 19, T.8 S., R.25 E., 5.5 miles (8.8 km) NNW of Warren, Carbon County, Montana. See Locality Map I.
Horizon: Unit VII, 52 feet (15.8 m) below Unit VIII.
Specimens collected: Tenontosaurus tilletti (YPM 5463); Sauropelta edwardsi (YPM 5521).


Sage Creek
YPM. 64-47
Pryor
Warren
Sage Creek
feet
0
1000
2000
0
300
600
meters
N

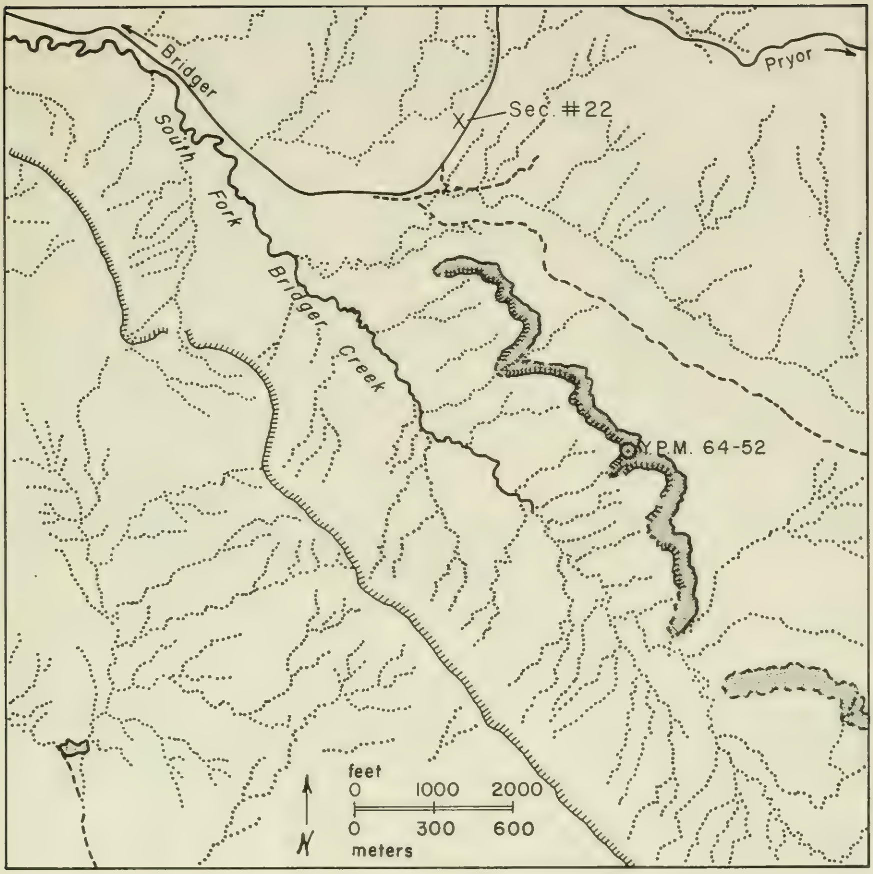
LOCALITY MAP I

YPM 64-49	SE 1/4 Sec. 12, T.8 S., R.24 E., 7 miles (11.2 km) NNW of Warren, Carbon County, Montana. See Locality Map J. Horizon: Unit VII. Specimen collected: Tenontosaurus tilletti (YPM 5465).


Y.P.M. 64-49
Warren
Sage
Creek
Warren
N
feet
0 1000 2000
0 300 600
meters

LOCALITY MAP J

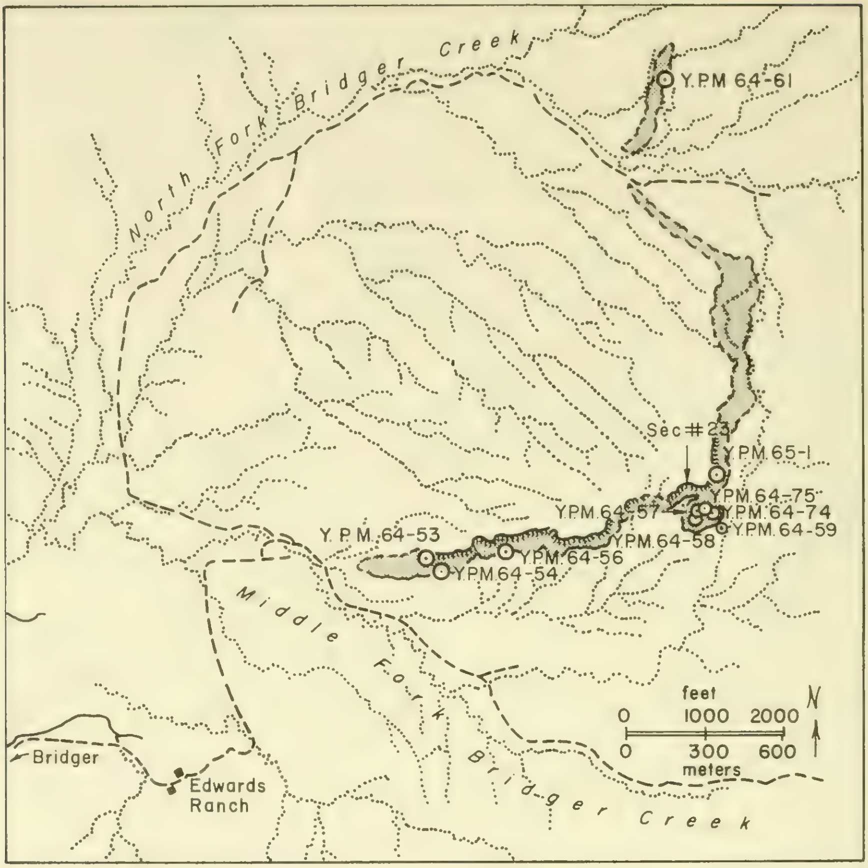
YPM 64-52	SE 1/4 Sec. 29, T.7 S., R.24 E., 2.5 miles (4 km) SSE of Tom Edwards ranch house, Carbon County, Montana. See Locality Map K. Horizon: Unit VII, 35 feet (10.5 m) above Unit VI. Specimens collected: Deinonychus antirrhopus (YPM 5287); Tenontosaurus tilletti (YPM 5467).
YPM 64-53	NW 1/4 Sec. 17, T.7 S., R.24 E., 1 mile (1.6 km) NE of Tom Edwards ranch house, Carbon County, Montana. See Locality Map L. Horizon: Unit VII, 27 feet (8.2 m) below Unit VIII. Specimen collected: Deinonychus sp (YPM 5397).


Bridger
Pryor
Sec. #22
South Fork Bridger Creek
Y.P.M. 64-52
feet
0 1000 2000
0 300 600
meters
N

LOCALITY MAP K

YPM 64-54 NW 1/4 Sec. 17, T.7 S., R.24 E., 1 mile (1.6 km) NE of Tom Edwards ranch and 60 yards (55 m) east of YPM 64-53, Carbon County, Montana. See Locality Map L.
Horizon: Unit V, 8 feet (2.4 m) below Unit VI.
Specimen collected: Tenontosaurus tilletti (YPM 5469).

YPM 64-56 NE 1/4 Sec. 17, T.7 S., R.24 E., 1.5 miles (2.4 km) NE of Tom Edwards ranch, 260 yards (238 m) west of YPM 64-54, Carbon County, Montana. See Locality Map L.
Horizon: Unit VII, 12 feet (3.6 m) above Unit VI.
Specimen collected: Naomichelys speciosa (YPM 5431).

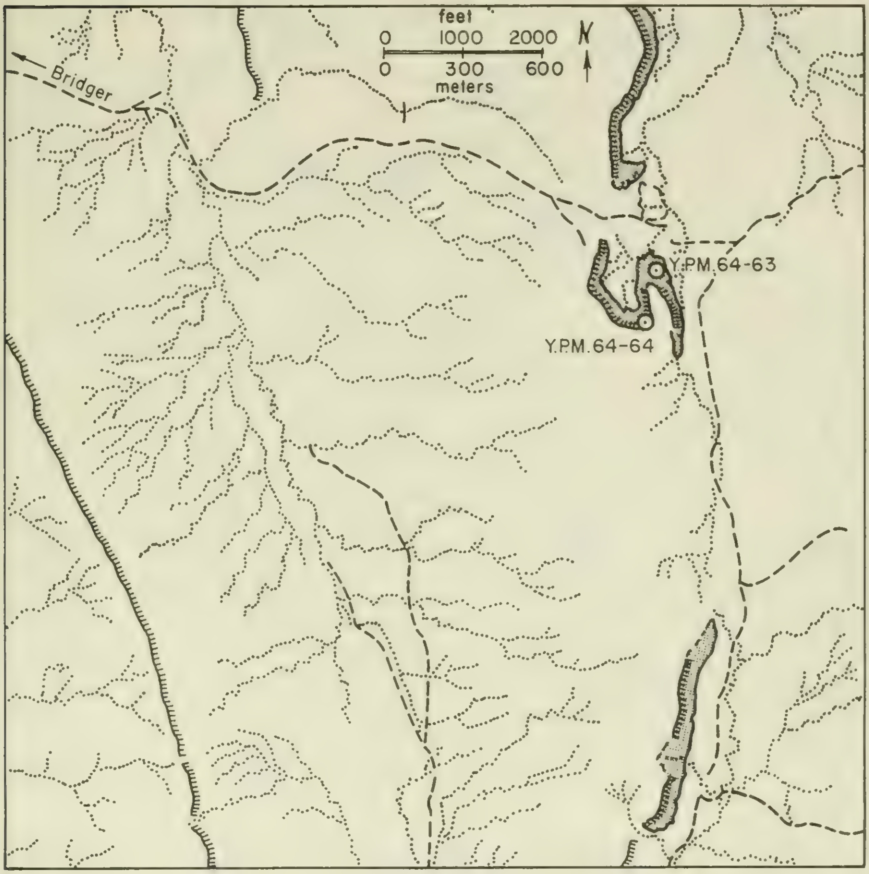


North Fork Bridger Creek
Y.P.M. 64-61
Sec #23
Y.P.M. 65-1
Y.P.M. 64-75
Y.P.M. 64-57
Y.P.M. 64-74
Y.P.M. 64-59
Y.P.M. 64-58
Y.P.M. 64-53
Y.P.M. 64-56
Y.P.M. 64-54
Middle Fork Bridger Creek
Bridger
Edwards Ranch
feet
0 1000 2000
0 300 600
meters
N

LOCALITY MAP L

YPM 64-57	NE 1/4 Sec. 17, T.7 S., R.24 E., 1.5 miles (2.4 km) NE of Tom Edwards ranch, Carbon County, Montana. See Locality Map L. Horizon: Unit VII, 4 feet (1.2 m) above Unit VI. Specimen collected: Tenontosaurus tilletti (YPM 5470).
YPM 64-58	NE 1/4 Sec. 17, T.7 S., R.24 E., 1.5 miles (2.4 km) NE of Tom Edwards ranch, on NW side of knob, Carbon County, Montana. See Locality Map L. Horizon: Unit VII, 4 feet (1.2 m) above Unit VI. Specimens collected: Tenontosaurus tilletti (YPM 5471, 5472).
YPM 64-59	NE 1/4 Sec. 17, T.7 S., R.24 E., 1.5 miles (2.4 km) NE of Tom Edwards ranch on east side of knob, Carbon County, Montana. See Locality Map L. Horizon: Unit V, 12 feet (3.6 m) below Unit VI. Specimen collected: Theropoda (Megalosauridae) (YPM 5285).
YPM 64-61	SE 1/4 Sec. 5, T.7 S., R.24 E., 2.25 miles (3.6 km) NE of Tom Edwards ranch, Carbon County, Montana. See Locality Map L. Horizon: Unit VII, 25 feet (7.5 m) above Unit VI. Specimen collected: Crocodilia? (YPM 5530).

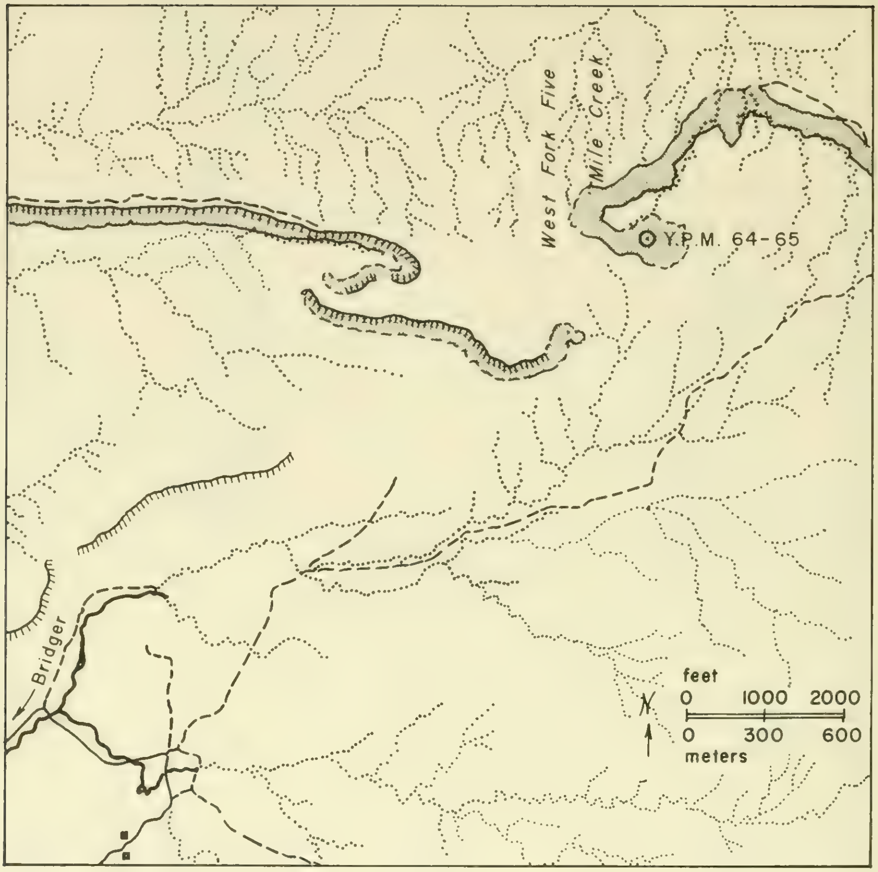
YPM 64-63 SE 1/4 Sec. 29, T.6 S., R.24 E., 220 yards (200 m) north of YPM 64-64, Carbon County, Montana. See Locality Map M.
Horizon: Unit VI, 7 feet (2.1 m) below Unit VII.
Specimens collected: Tenontosaurus tilletti (YPM 5468, 5480); Crocodilia (YPM 5293).



LOCALITY MAP M

YPM 64-64 SE 1/4 Sec. 29, T. 6 S., R. 24 E., 4.25 miles (6.8 km) NNE of Tom Edwards ranch, 3.75 miles (6 km) ESE of Bridger railroad station, Carbon County, Montana. See Locality Map M.
Horizon: Unit VII, 18 feet (5.5 m) above Unit VI.
Specimens collected: Deinonychus antirrhopus (YPM 5279); Tenontosaurus tilletti (YPM 5461, 5523).

YPM 64-65 SW 1/4 Sec. 34, T.5 S., R.24 E., 2.5 miles (4 km) NE of Bluewater Creek Fish Hatchery, Carbon County, Montana. See Locality Map O.
Horizon: Unit VII, 25 feet (7.6 m) above Unit VI.
Specimen collected: Deinonychus antirrhopus (YPM 5278).



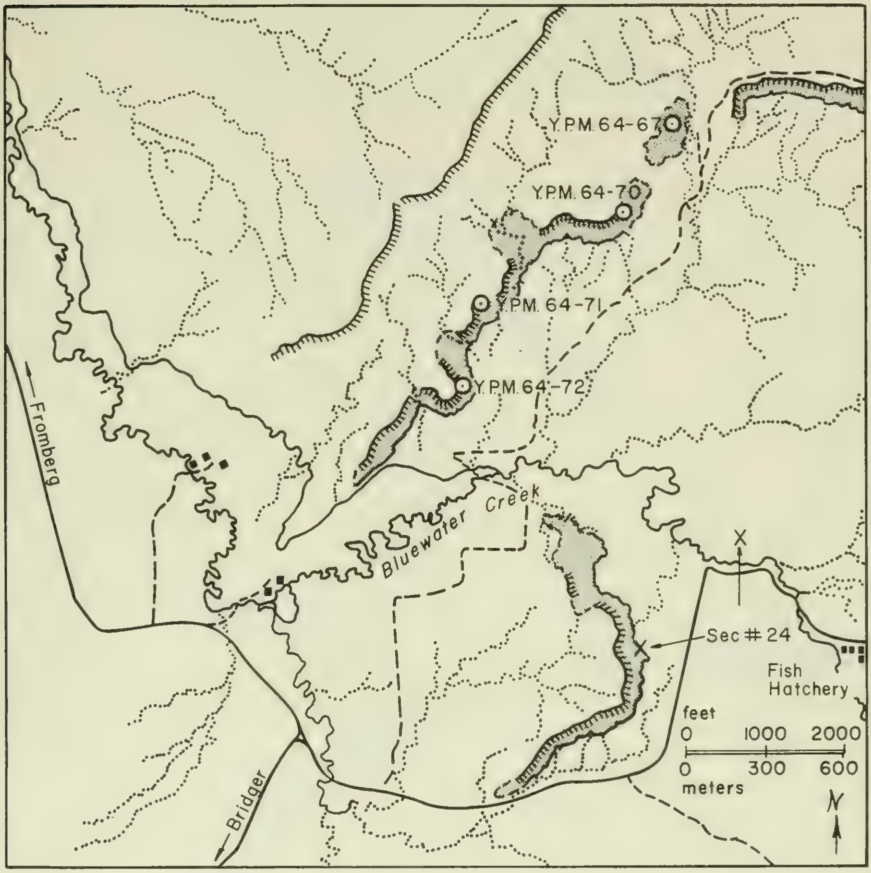
LOCALITY MAP O

YPM 64-67 SE 1/4 Sec. 31, T.5 S., R.24 E., 5 miles (8 km) NE of Bridger railroad station, Carbon County, Montana. See Locality Map N.
Horizon: Unit VII.
Specimens collected: Deinonychus? (YPM 5289); Tenontosaurus tilletti (YPM 5473); Sauropelta edwardsi (YPM 5520).

YPM 64-70 NE 1/4 Sec. 5, T.6 S., R.24 E., 1.25 miles (2 km) NNW of Bluewater Creek Fish Hatchery and 650 yards (600 m) NE of YPM 64-71, Carbon County, Montana. See Locality Map N.
Horizon: Unit VII.
Specimen collected: Crocodilia (YPM 5292).

YPM 64-71 NW 1/4 Sec. 5, T.6 S., R.24 E., 4.5 miles (7.2 km) NE of Bridger railroad station, 0.5 mile (0.8 km) north of Bluewater Creek, Carbon County, Montana. See Locality Map N.
Horizon: Unit VII, 9 feet (2.7 m) above Unit VI.
Specimens collected: Tenontosaurus tilletti (YPM 5475, 5481); Crocodilia (YPM 5429).

YPM 64-72 SW 1/4 Sec. 5, T.6 S., R.24 E., 0.25 mile (0.4 km) south of YPM 64-71, Carbon County, Montana. See Locality Map N.
Horizon: Unit VII, 5 feet (1.5 m) above Unit VI.
Specimens collected: *Deinonychus antirrhopus* (YPM 5280); *Tenontosaurus tilletti* (YPM 5474).


YPM 64-67
YPM 64-70
YPM 64-71
YPM 64-72
Fromberg
Bluewater Creek
Sec # 24
Fish Hatchery
feet
0 1000 2000
0 300 600
meters
N
Bridger

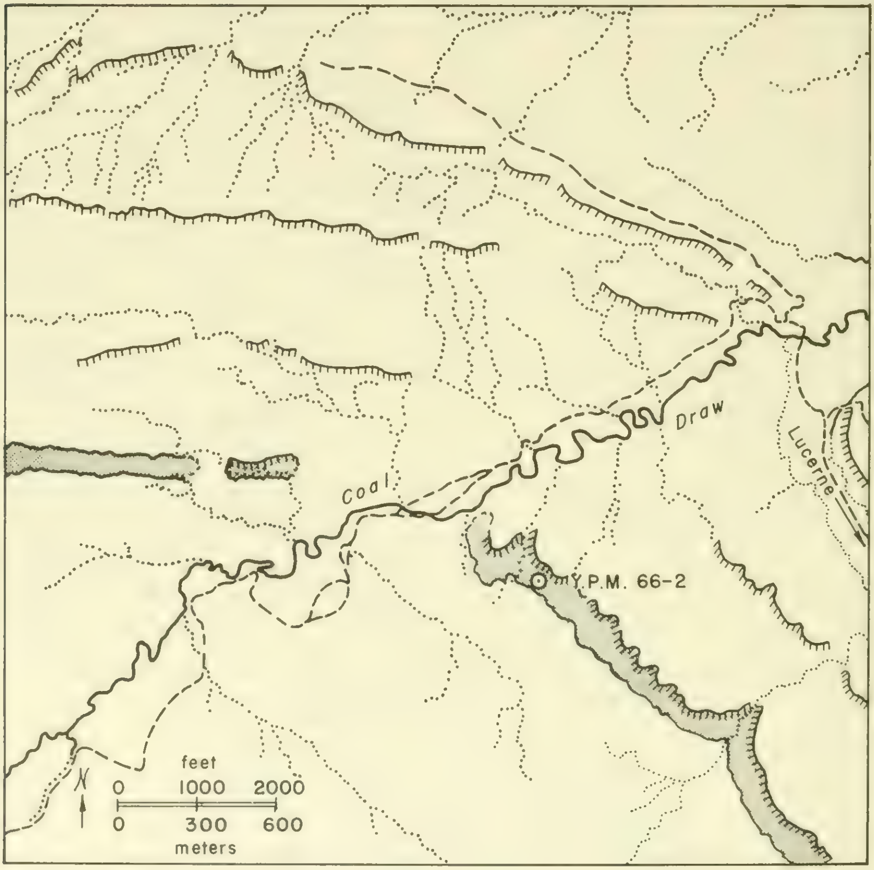
LOCALITY MAP N

YPM 64-74 NE 1/4 Sec. 17, T.7 S., R.24 E., 1.5 miles (2.4 km) NE of Tom Edwards ranch, on north side of knob, Carbon County, Montana. See Locality Map L.
Horizon: Unit VII, 14 feet (4.2 m) above Unit VI.
Specimens collected: *Deinonychus*? (YPM 5291); *Tenontosaurus tilletti* (YPM 5478).

YPM 64-75 NE 1/4 Sec. 17, T.7 S., R.24 E., 1.5 miles (2.4 km) NE of Tom Edwards ranch on north side of knob, Carbon County, Montana. See Locality Map L.
Horizon: Unit VII, 14 to 17 feet (4.2 to 5.1 m) above Unit VI.
Specimens collected: *Deinonychus antirrhopus* (YPM 5201-5271); *Tenontosaurus tilletti* (YPM 5466).

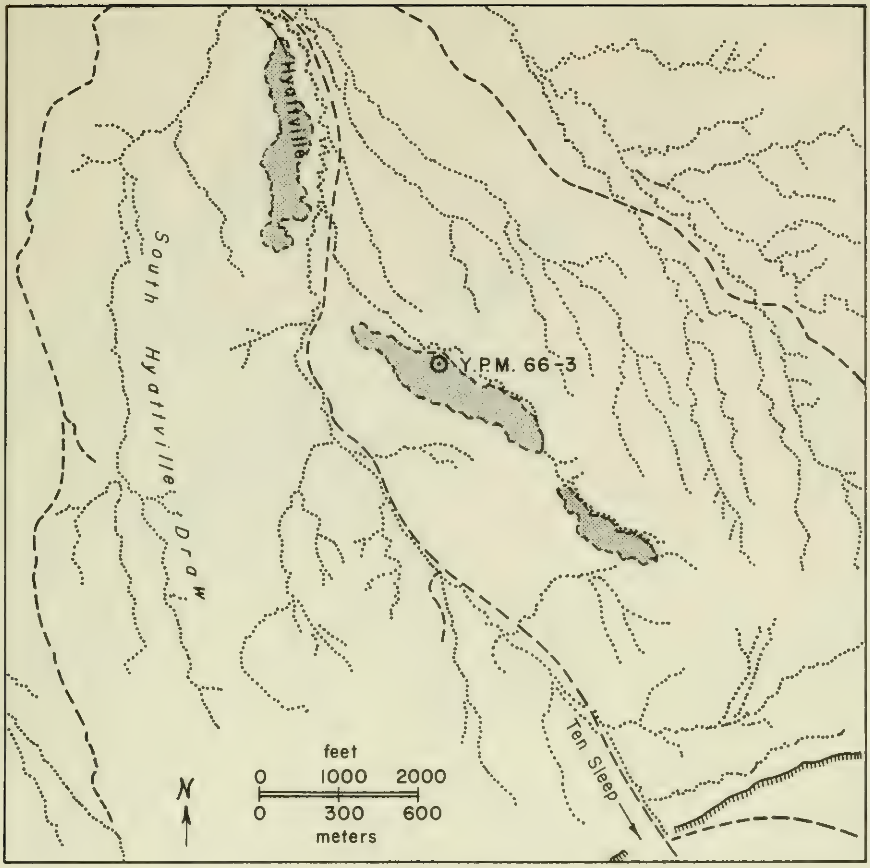
YPM 65-1 SE 1/4 Sec. 8, T.7 S., R.24 E., 1.75 miles (2.8 km) NE of Tom Edwards ranch, 200 yards (183 m) north of knob, Carbon County, Montana. See Locality Map L.
Horizon: Unit VII, 25 feet (7.6 m) above Unit VI.
Specimen collected: Tenontosaurus tilletti (YPM 5462).

YPM 66-2 NW 1/4 Sec. 36, T.44 N., R.96 W., 2.5 miles (4 km) NE of junction of State Highway 120 with Hamilton Dome road, Hot Springs County, Wyoming. See Locality Map A.
Horizon: Unit VII, 52 feet (15.8 m) below Unit VIII.
Specimen collected: Crocodilia (YPM 5436).



LOCALITY MAP A

YPM 66-3 NW 1/4 Sec. 17, T.49 N., R.89 W., 2 miles (3.2 km) SE of Hyattville, Big Horn County, Wyoming. See Locality Map B.
Horizon: Unit VII, at least 30 feet (9 m) below Unit VIII.
Specimens collected: Glyptops pervicax? (YPM 5435); Deinonychus? (YPM 5290).

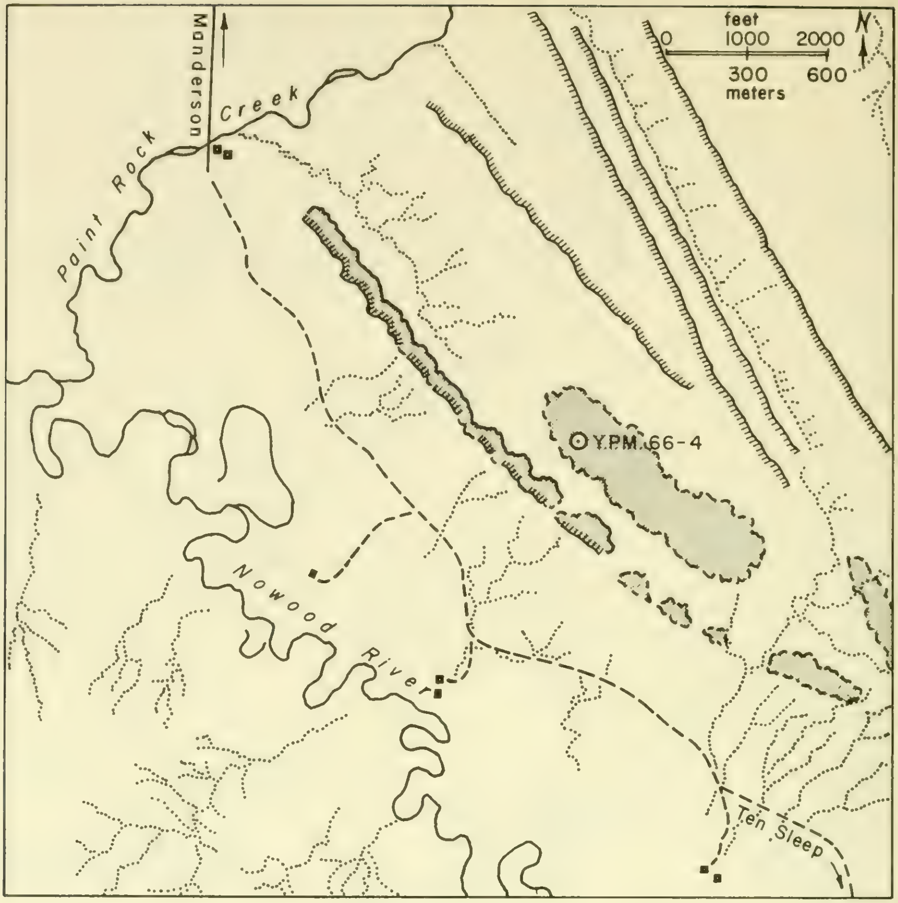

Hyattville
South Hyattville Draw
Y.P.M. 66-3
Ten Sleep
N
feet
0 1000 2000
0 300 600
meters

LOCALITY MAP B

YPM 66-4 NW 1/4 Sec. 29, T.49 N., R.90 W., 1 mile (1.6 km) SE of bridge over Paint Rock Creek, Big Horn County, Wyoming. See Locality Map C.

Horizon: Unit VII.

Specimen collected: Tenontosaurus? (YPM 5484).


Manderson
Paint Rock Creek
Nowood River
Ten Sleep
Y.P.M. 66-4
feet
0
1000
2000
300
600
meters
N

LOCALITY MAP C

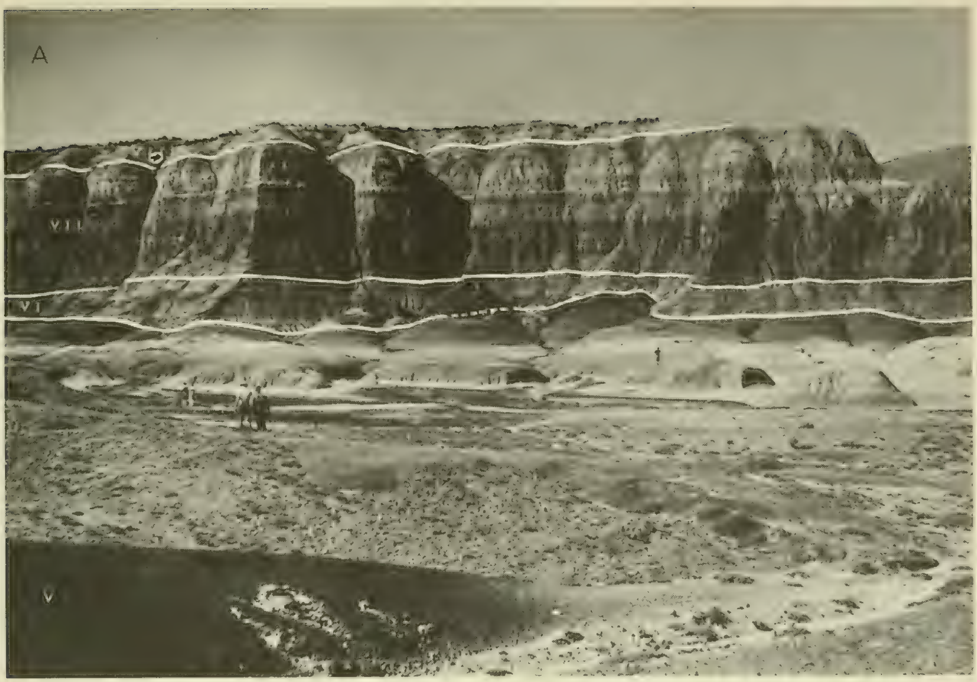
PLATES

PLATE 1A

Exposures of the upper part of the Morrison-Cloverly section (Units V, VI and VII) plus the lower sands (Unit VIII) of the Sykes Mountain Formation ("rusty beds") approximately 0.5 mile (0.8 km) north of the type Cloverly section, west of Beaver Creek, Big Horn County, Wyoming. Units VI and VII equal Darton's original Cloverly Formation. Unit V the top of his Morrison Formation. The light-colored stratum just beyond the distant figure is the fragmental tuff.

PLATE 1B

Cloverly, Sykes Mountain and Thermopolis Formations exposed 4 miles (6.4 km) north of the type section of the Cloverly Formation. The hill is situated immediately west of the North Fork of Beaver Creek in Big Horn County, Wyoming. The Sykes Mountain Formation extends from the base of Unit VIII to the dark gray zone above. The base of the Cloverly Formation as defined in this report is concealed here, but probably lies slightly above the level of the automobile in the left foreground. The light-colored fragmental tuff is prominent just below Unit VI.


A
VII
VI
V

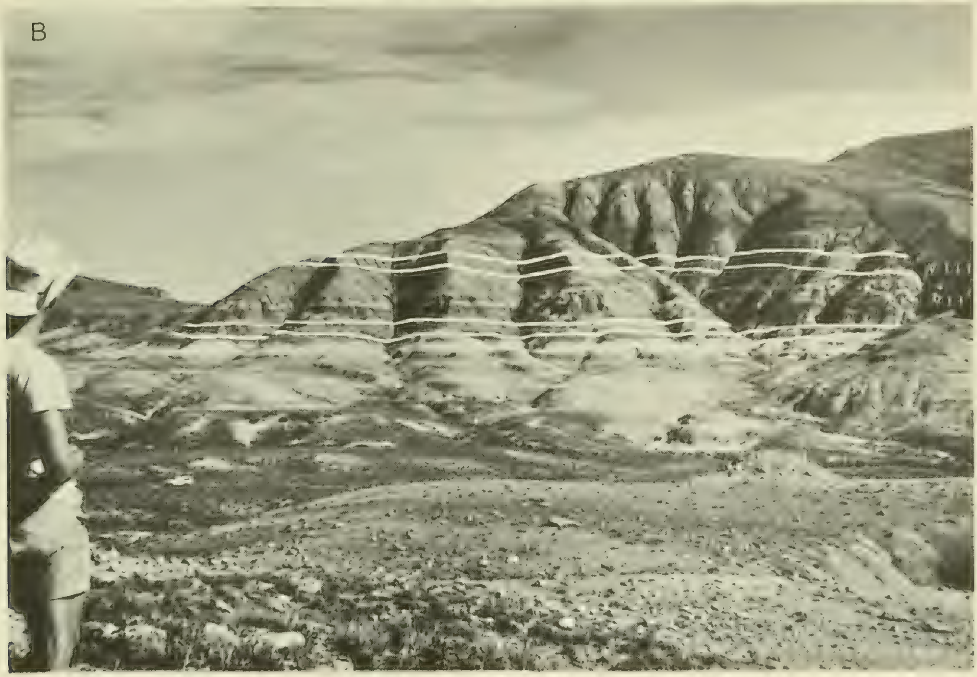
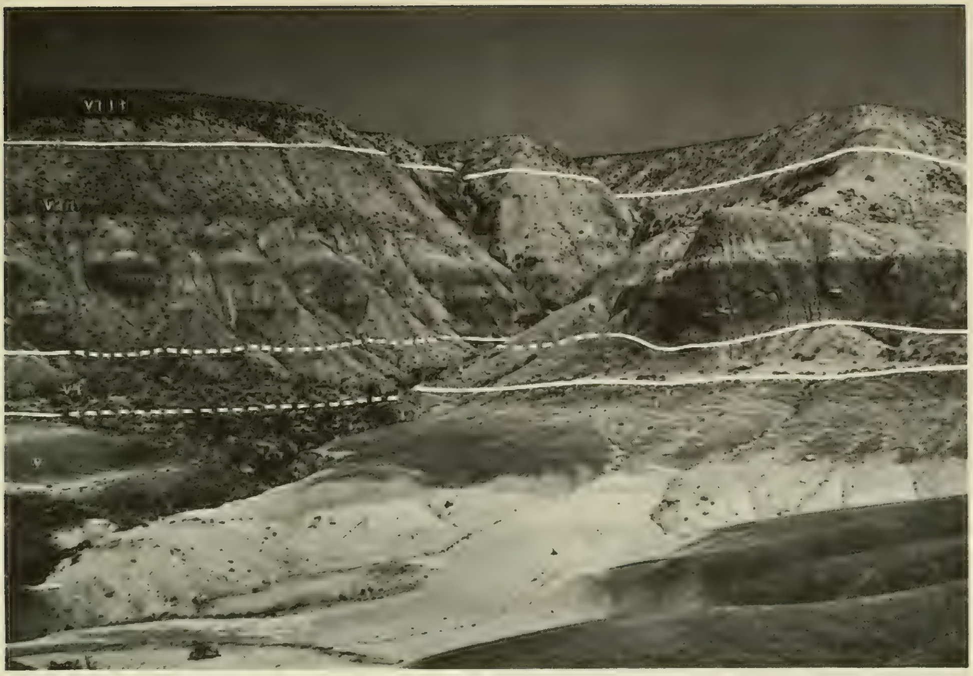

B
VIII
VII

PLATE 2A

Exposures of the upper part (Units V, VI and VII) of the Morrison-Cloverly section approximately 3 miles (4.8 km) north of the Cloverly type section, near the headwaters of East Branch of Bear Creek, Big Horn County, Wyoming. The thickness of Units VI and VII (Darton's Cloverly) is about 115 feet (35 m) here. The white tuff is exposed in the foreground.

PLATE 2B

Upper part of the Morrison-Cloverly section at outcrops 5 miles (8 km) north of the Cloverly type section on East Branch of Bear Creek, Big Horn County, Wyoming. Notice the local variation in thickness of the channel sand (Unit VI) and the discordance between the base and the stratification of Unit VII. The relief of the contact between VI and VII resulted from scouring and removal of material prior to deposition of the clay and silt of Unit VII.


VIII
VII
VI
V

B

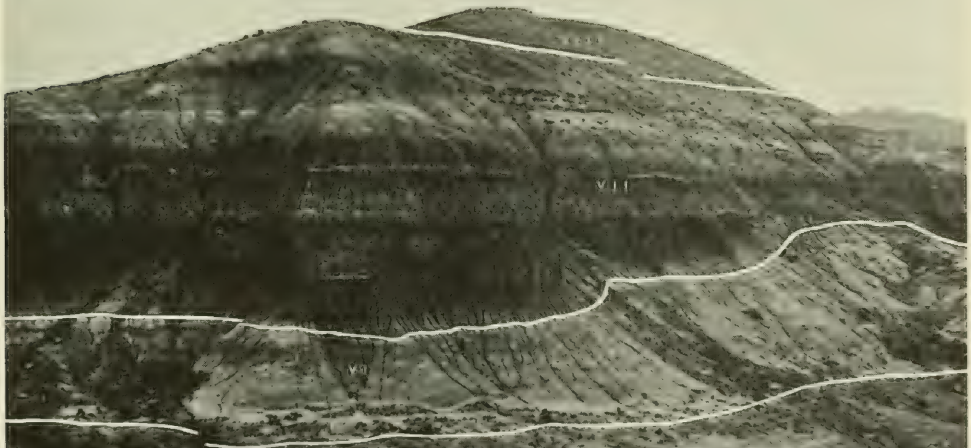
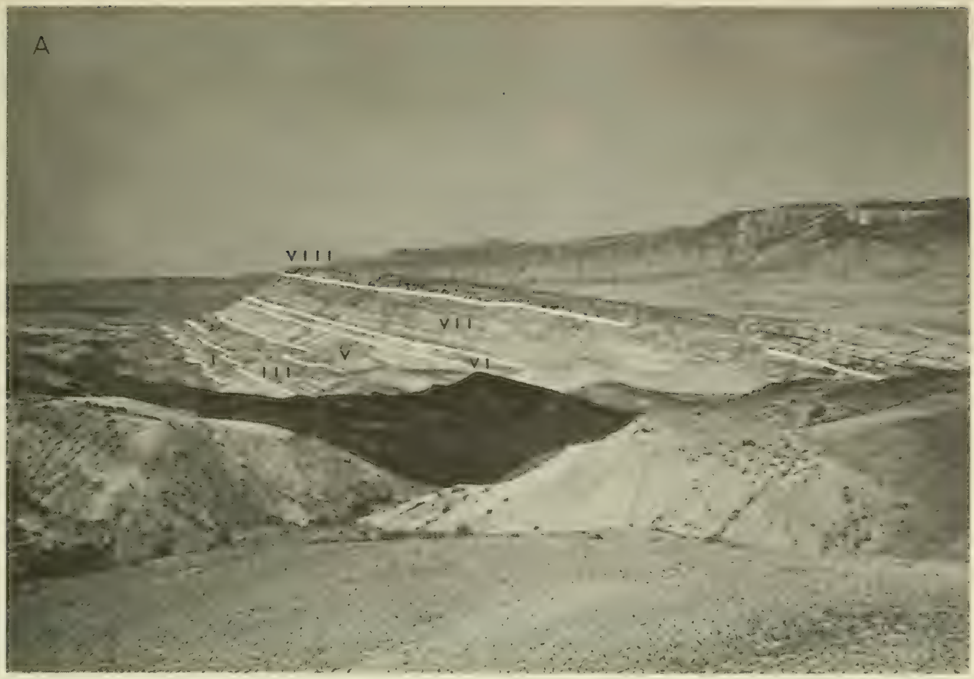

VIII
VII
VI
V

PLATE 3A

The complete nonmarine Morrison-Cloverly section exposed in the prominent ridge immediately south of Crystal Creek, 13 miles (20.8 km) due north of Greybull, Wyoming. The Sundance Formation is extensively exposed beneath Unit I at the base of the bluff. Unit VIII caps the ridge, but to the east and south 250 to 350 feet (76 to 106 m) of black, marine, Thermopolis Shale overlies Unit VIII (black exposures in the foreground). The Bighorn Mountains are in the distance.

PLATE 3B

Same exposures as in 3A viewed from the opposite direction. This photograph was found in Barnum Brown's files and was made available by E. H. Colbert of the American Museum. It is included here to show Brown's interpretation of this section. The transitional sandstone (= Greybull sandstone) corresponds to the basal part of the Sykes Mountain Formation ("rusty beds") of Moberly. The Cloverly and Lakota (Units VII and VI) equal the Cloverly Formation as described by Darton at the Cloverly Post Office site. The fragmental tuff is discernible below Brown's "Lakota" sandstone. Unit I cannot be seen from this vantage point, but probably constitutes the lowest part of the section labeled Morrison. Crystal Creek is in the foreground.


A
VIII
VII
I
III
V
VI

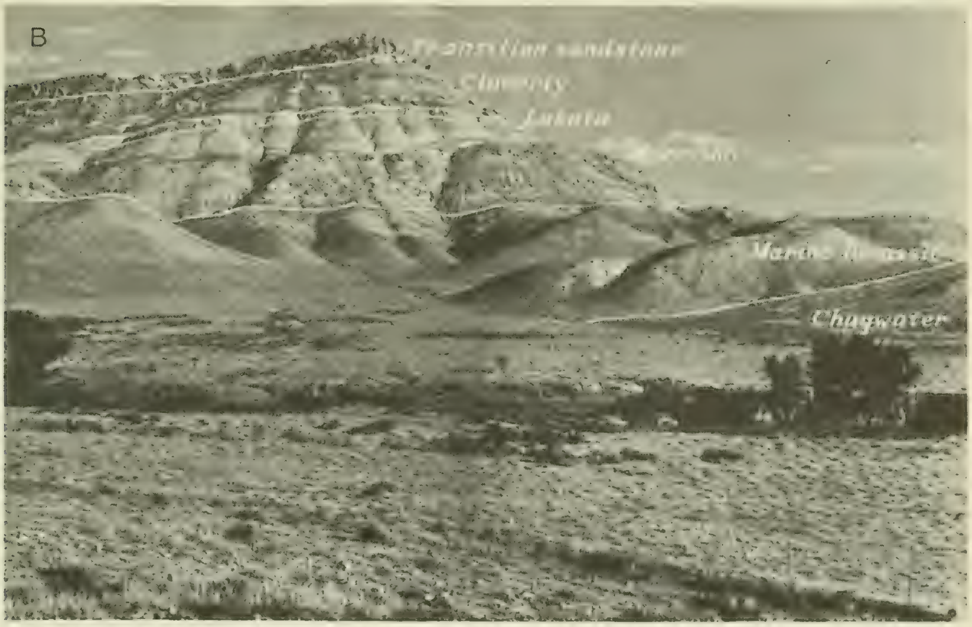

B
Transition sandstone
Cloverly
Lakota
Morrison
Marine Jurassic
Chugwater

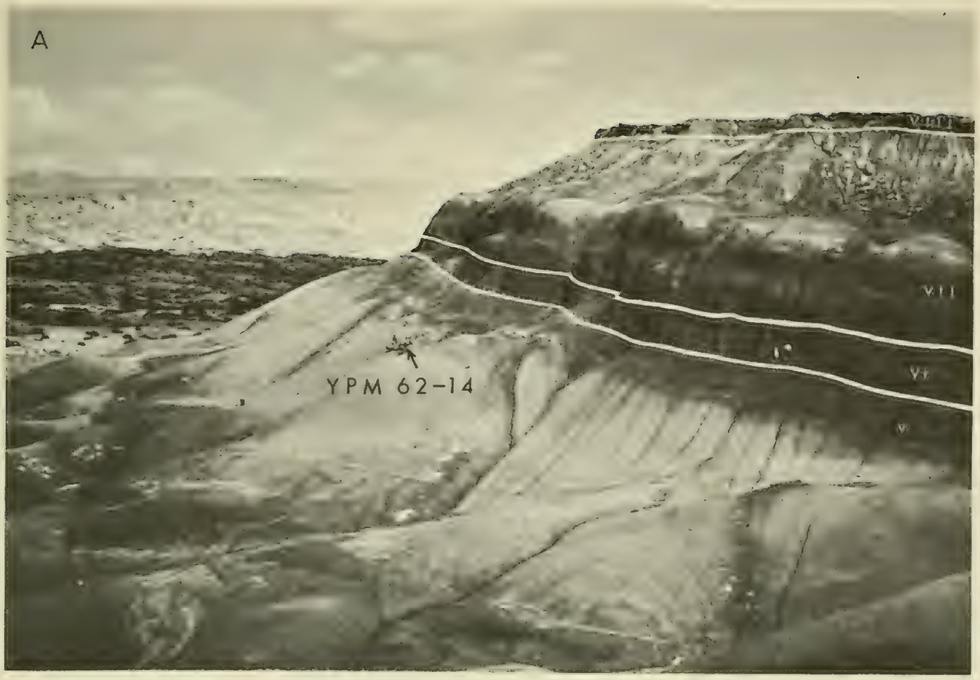
PLATE 4A

Site of one of the Yale localities of the 1962 expedition in the Cloverly ridge immediately east of Crooked Creek, 10.5 miles (16.8 km) northeast of Lovell, Wyoming. This was one of several sites in the upper part of Unit V, all of which produced fossil vertebrate remains identical to those collected from Units VI and VII. Notice the absence of the tuff within Unit V. The Bighorn Mountains are in the distance.

PLATE 4B

The upper Cloverly cliffs east of Crooked Creek at the site of three Yale localities. These exposures are approximately one mile (1.6 km) northwest of the site illustrated in 4A. The three sites shown here and others nearby produced remains of sauropods, ornithopods and a primitive acanthopholid, chiefly from the lower part of Unit VII. Section No. 20 was measured here and in adjacent exposures. (See Locality Map H.)

A


VIII
VII
VI
V
YPM 62-14

B

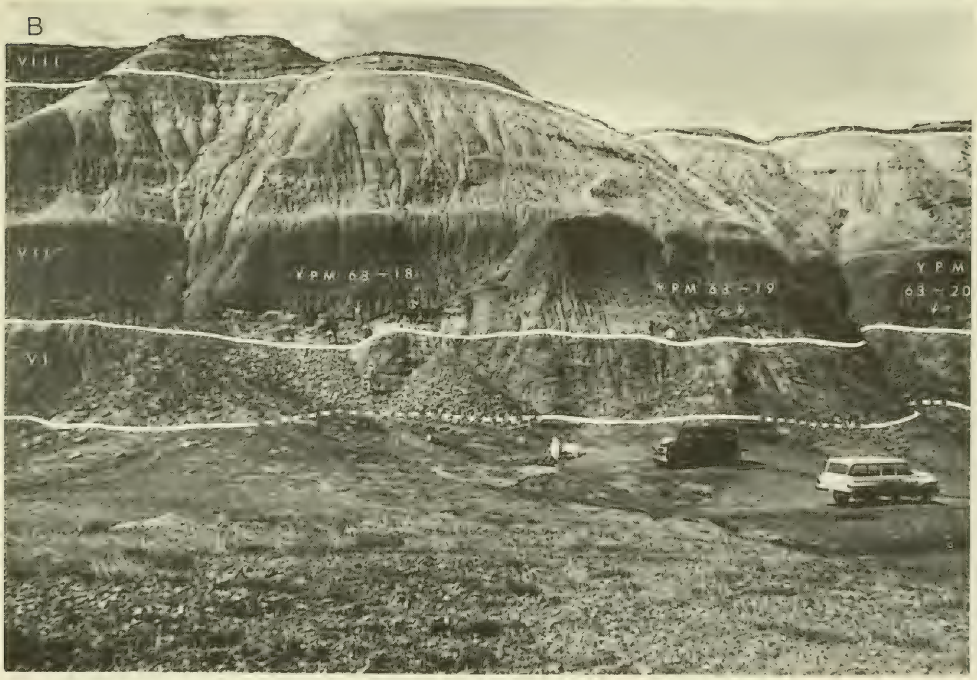

VIII
VII
YPM 63-18
YPM 63-19
YPM 63-20
VI

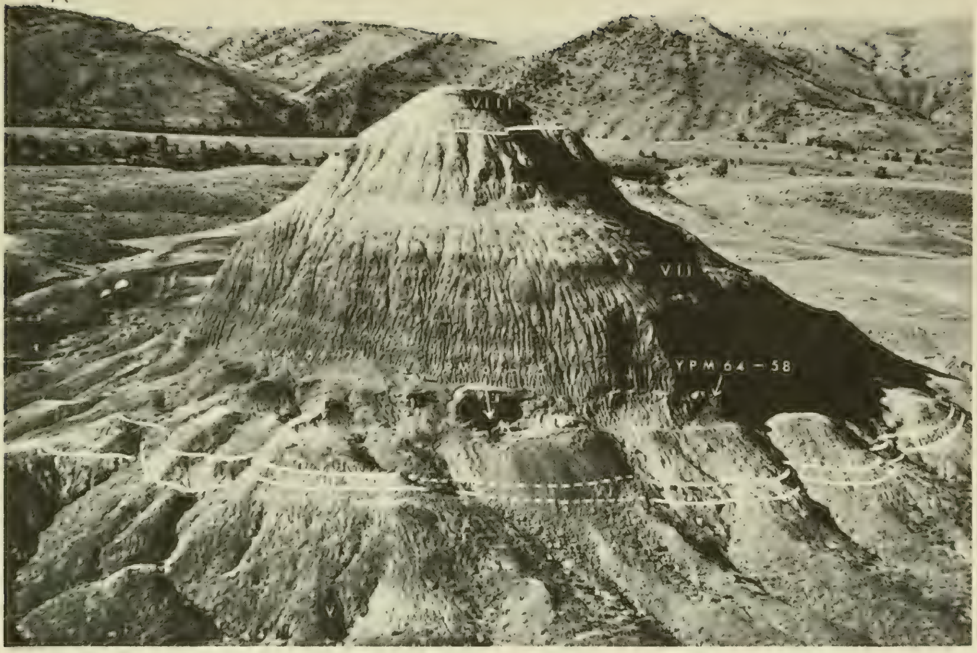
PLATE 5A

The site of several Yale quarries immediately north of Red Dome, 7.5 miles (12 km) southeast of Bridger, Montana (see Locality Map L). The prominent quarry in the center foreground (YPM 64-75) is the site of nearly all known remains of the unusual theropod, *Deinonychus*. Section No. 23 was measured at the photographer's vantage point.

PLATE 5B

The complete nonmarine section exposed near the junction of Buster and Beauvais Creeks, Crow Indian Reservation, Montana. The grassy slope in the foreground is a dip slope lying 20 feet (6.0 m) or less above the top of the Sundance Formation. Good exposures of the Sundance occur just to the right of this photograph adjacent to the stream in the foreground. The channel sand (Unit VI), which is marked but not labeled here, is discontinuous. Section No. 27 was measured at these exposures. (See Locality Map U.)

A


VIII
VII
YPM 64-58
V

B

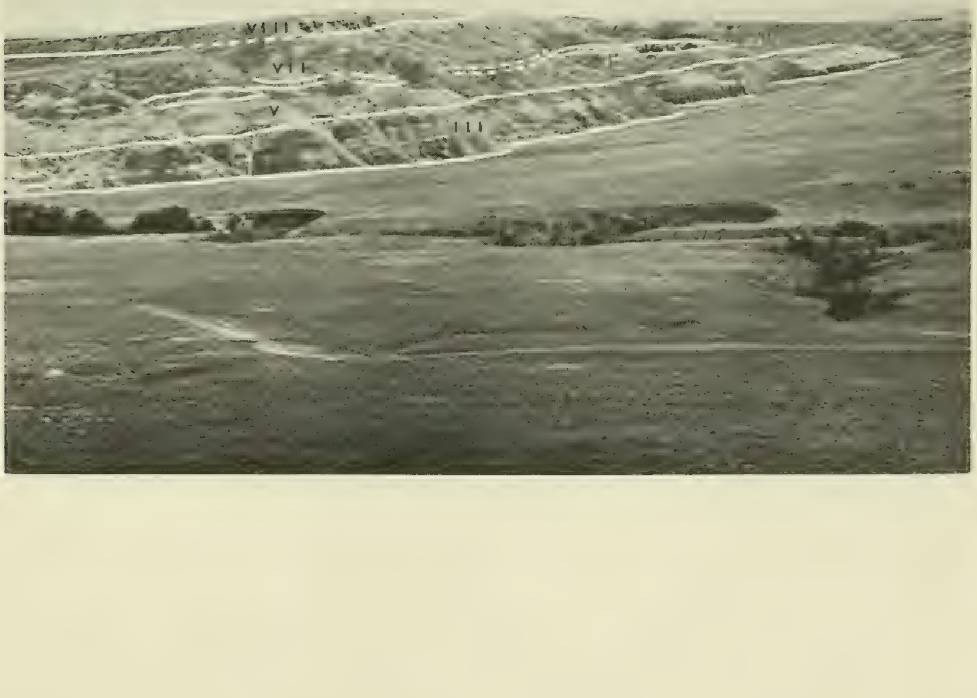
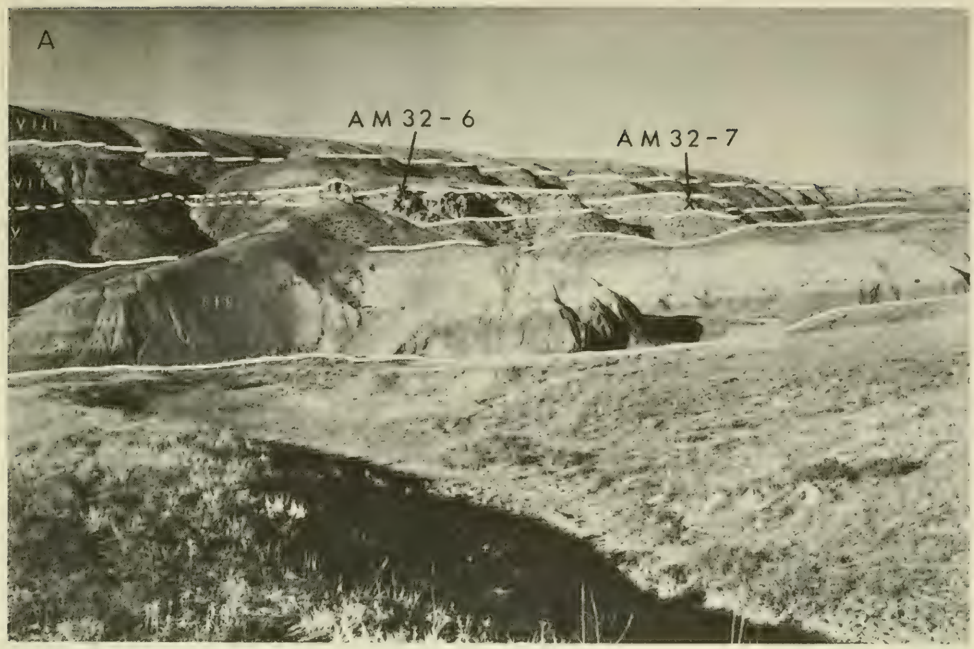

VIII
VII
V
III

PLATE 6A

Upper part of the Morrison-Cloverly section exposed 0.25 mile (0.4 km) east of the exposures shown in Plate 5B, illustrating the variable thickness and discontinuous nature of Unit VI and the location of two American Museum sites. Photo by Barnum Brown, made available by E. H. Colbert.

PLATE 6B

Aerial view of the Cashen ranch area, Crow Indian Reservation, Montana, approximately 30 miles (48 km) southeast of Billings. This photograph was published in *Natural History* (vol. 48, 1941), but without identification of the localities marked. Each of these sites was examined during the 1964 Yale expedition and precise stratigraphic levels recorded. All except AM 31-5 occur in Unit V. No record remains of the collections (if any) that were made at the two doubtful sites at right center. The collections from the other sites are recorded elsewhere in this report. Fragments of belemnites and *Gryphaea* were collected in the depression in the center of the photograph (see page 46).


A
VIII
AM 32-6
AM 32-7
VII
V
III

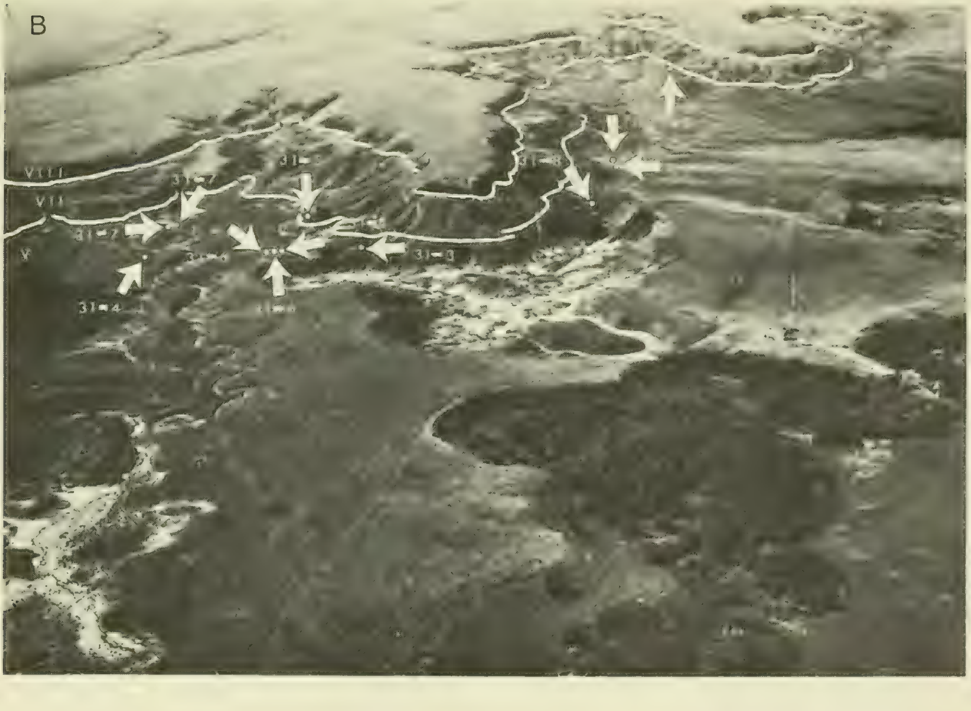
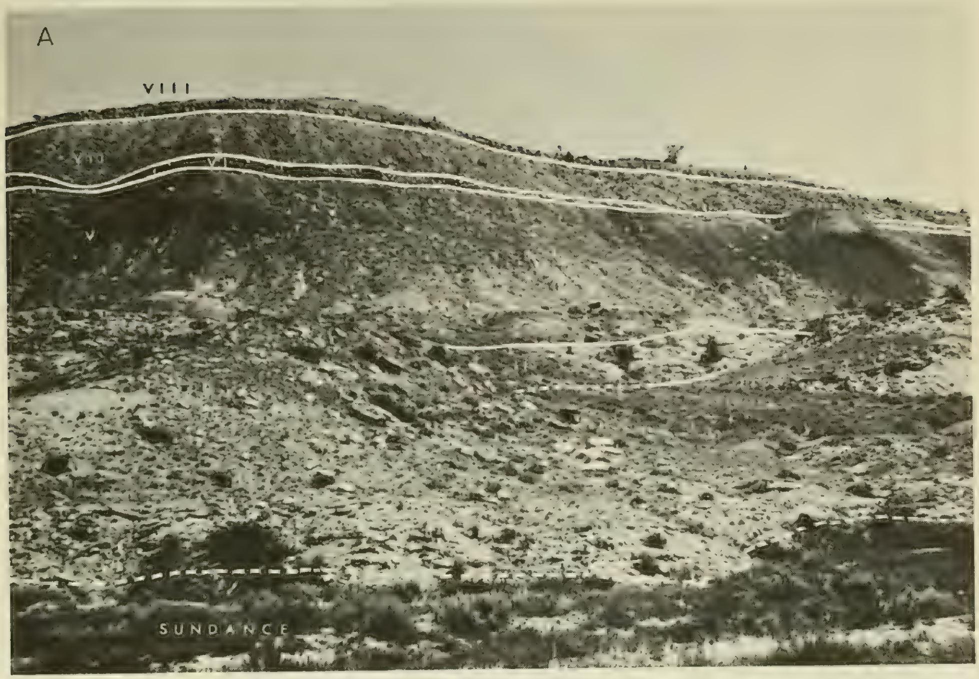

B
VIII
31-7
VII
31-7
V
31-4
31-3

PLATE 7A

The Morrison-Cloverly hogback immediately south of Cody, Wyoming. This is the site of measured Section No. 1. The dashed line marks the approximate level of the contact between the Sundance Formation and the overlying nonmarine strata. Units VI and VII correspond to the Cloverly Formation as defined by Darton on the eastern side of the Bighorn Basin. In this report the Cloverly Formation is extended to include the underlying bentonitic claystone (Unit V), after Moberly (1960).

PLATE 7B

The inner cliffs of the north rim of Middle Dome near Harlowton, Montana. Recorded here is the site of *Microvenator* (Locality AMNH 33-1). The section exposed here is difficult to correlate with exposures in the study area. The transition sandstone (Brown's label) almost certainly corresponds at least in part with our Unit VIII. The underlying claystone section presumably represents Units VII and V (there is no sign of Unit VI). The section shown here probably is referable in its entirety to the Cloverly Formation, as that term is used in this report, the Morrison Formation being entirely concealed or absent. Photo by Barnum Brown, made available by E. H. Colbert.


A
VIII
VII
VI
V
SUNDANCE

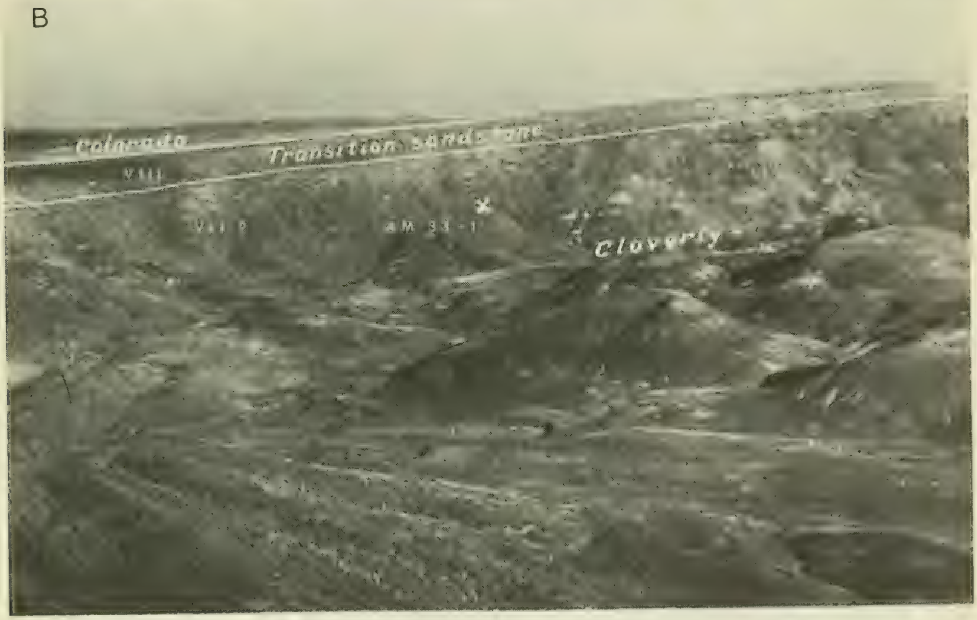
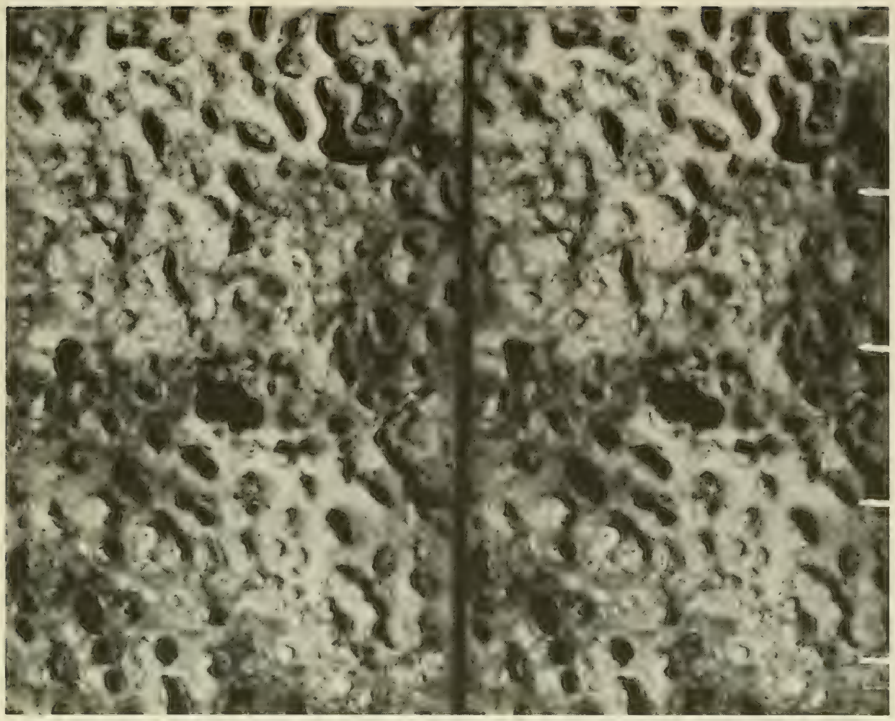

B
Colorado
Transition sandstone
VIII
VII ?
AM 33-1
Cloverly

PLATE 8

Stereo photographs (enlarged 20X) of the surface texture of the indeterminate specimen (A) "*Cretaceous browni*" (AMNH 8661) and the type specimen (B) of *Ceratodus frazieri* (YPM 5276). White dashes at right indicate mm.

A



B

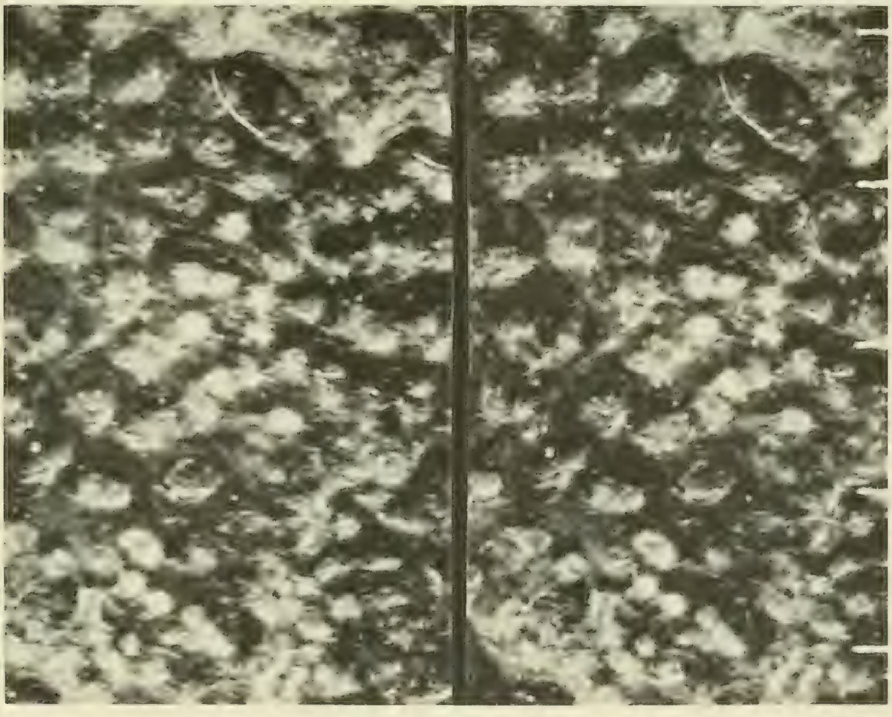


PLATE 9

A) Type tooth plate of *Ceratodus frazieri* (YPM 5276); B) type tooth plate of *Ceratodus guentheri* (YPM 205); C, D) mandibular and maxillary tooth plates (YPM 3201) referred to *Ceratodus guentheri*; E) type entoplastron of *Naomichelys speciosa* (AMNH 6136); F) right epiplastron of *Naomichelys speciosa* (YPM 5358); G) left humerus, distal end in external view, of indeterminate chelonian (YPM 4903); H) same in ventral view; I) proximal end of a right humerus (YPM 4900) of a testudinid(?), proximal view; J) same in dorsal view; K) distal end of same humerus (YPM 4900) in external view; L) same in ventral view. Scales indicate cm.

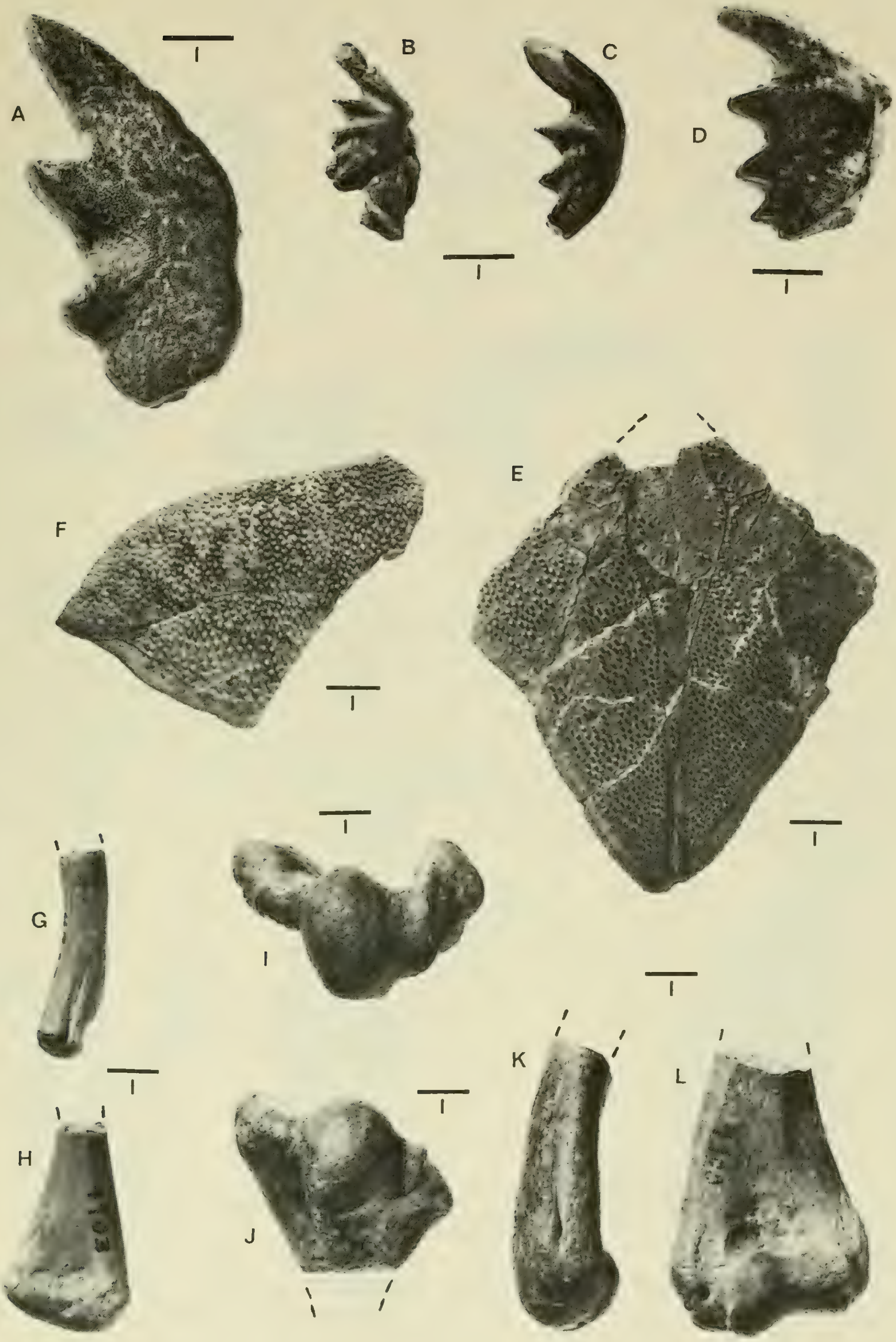
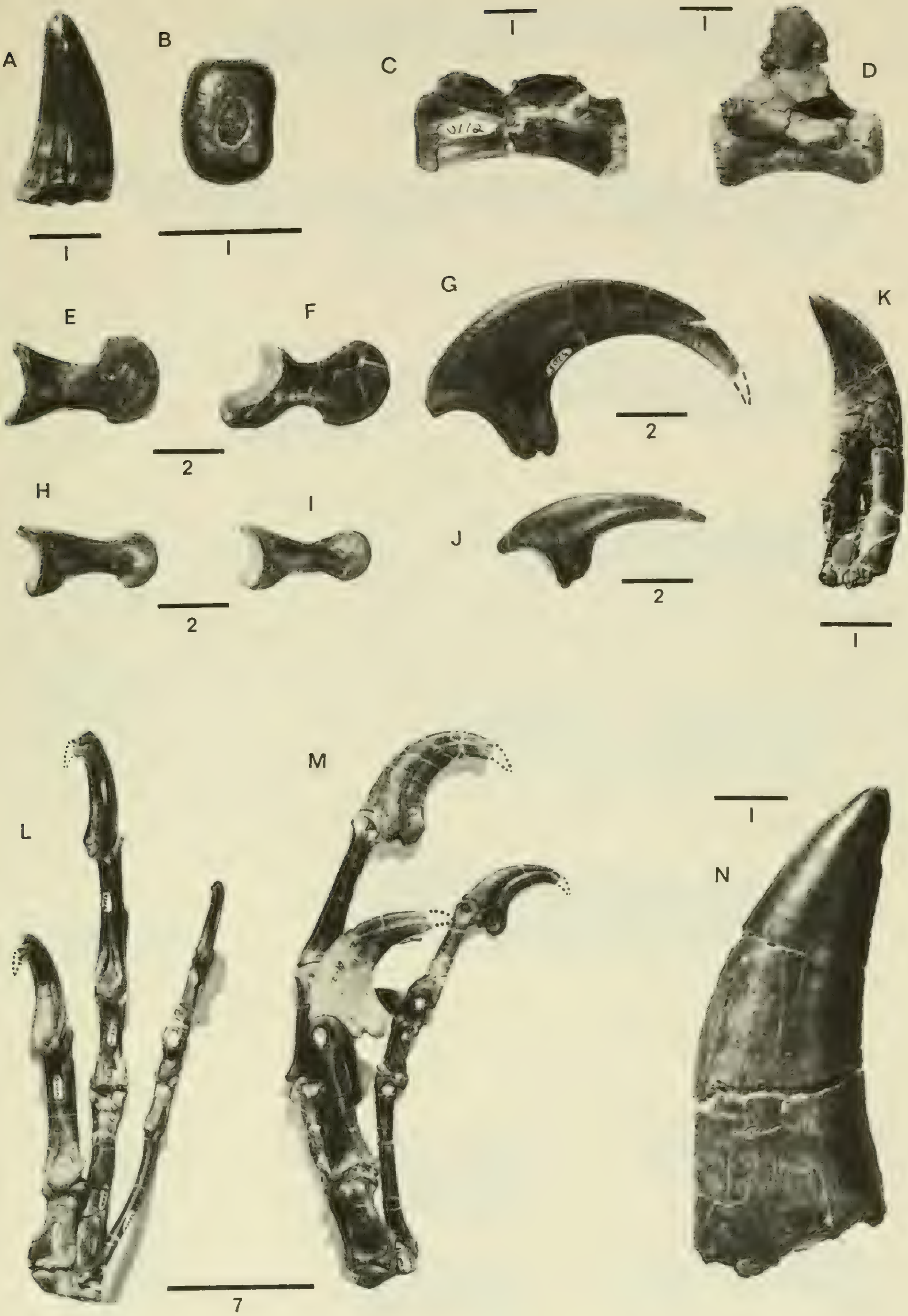

A
1
B
C
D
1
1
E
F
1
1
1
G
I
1
H
J
1
K
L
1

PLATE 10

A) "*Goniopholis*"-type tooth (YPM 4901); B) crushing-type crocodilian tooth (YPM 5342) in crown view; C, D) two crocodilian caudal vertebrae (YPM 5172 and 5110) in lateral view; E, F and G) proximal phalanx, distal phalanx and ungual, left pes digit II of *Deinonychus antirrhopus* (YPM 5205) in medial view; H, I and J) intermediate phalanx, distal phalanx and ungual of left pes digit III of *Deinonychus antirrhopus* (YPM 5205) in medial view; K) maxillary tooth of *Deinonychus antirrhopus* (YPM 5210); L) left manus and carpus of *Deinonychus antirrhopus* (YPM 5206) in palmar view; M) same in medial view; N) indeterminate theropod tooth (YPM 5377). Scales indicate cm.



1
1
A
B
C
D
1
1
G
K
E
F
2
2
H
I
J
2
2
1
M
L
1
N
7

PLATE 11

A and B) Left metatarsal IV, type of *Ornithomimus velox* (YPM 542) in medial and ventral views; C) left metatarsal II, type of *Ornithomimus velox* (YPM 542) in medial view; D and E) pes ungual, type of *Ornithomimus velox* (YPM 542) in dorsal and medial views; F) left metatarsal IV, *Ornithomimus* sp. (YPM 5284) in medial view; G) same in ventral view; H) left metatarsal II, *Ornithomimus* sp. (YPM 5174) in medial view; I and J) pes ungual. *Ornithomimus* sp. (YPM 5286) in dorsal and medial views; K) isolated theropod tooth (YPM 5366), possibly of *Microvenator celer;* L and M) cervical neural arch, type, *Microvenator celer* (AMNH 3041) in lateral and dorsal views; N) cervical centrum, type, *Microvenator celer* (AMNH 3041) in lateral view. Scales indicate cm.

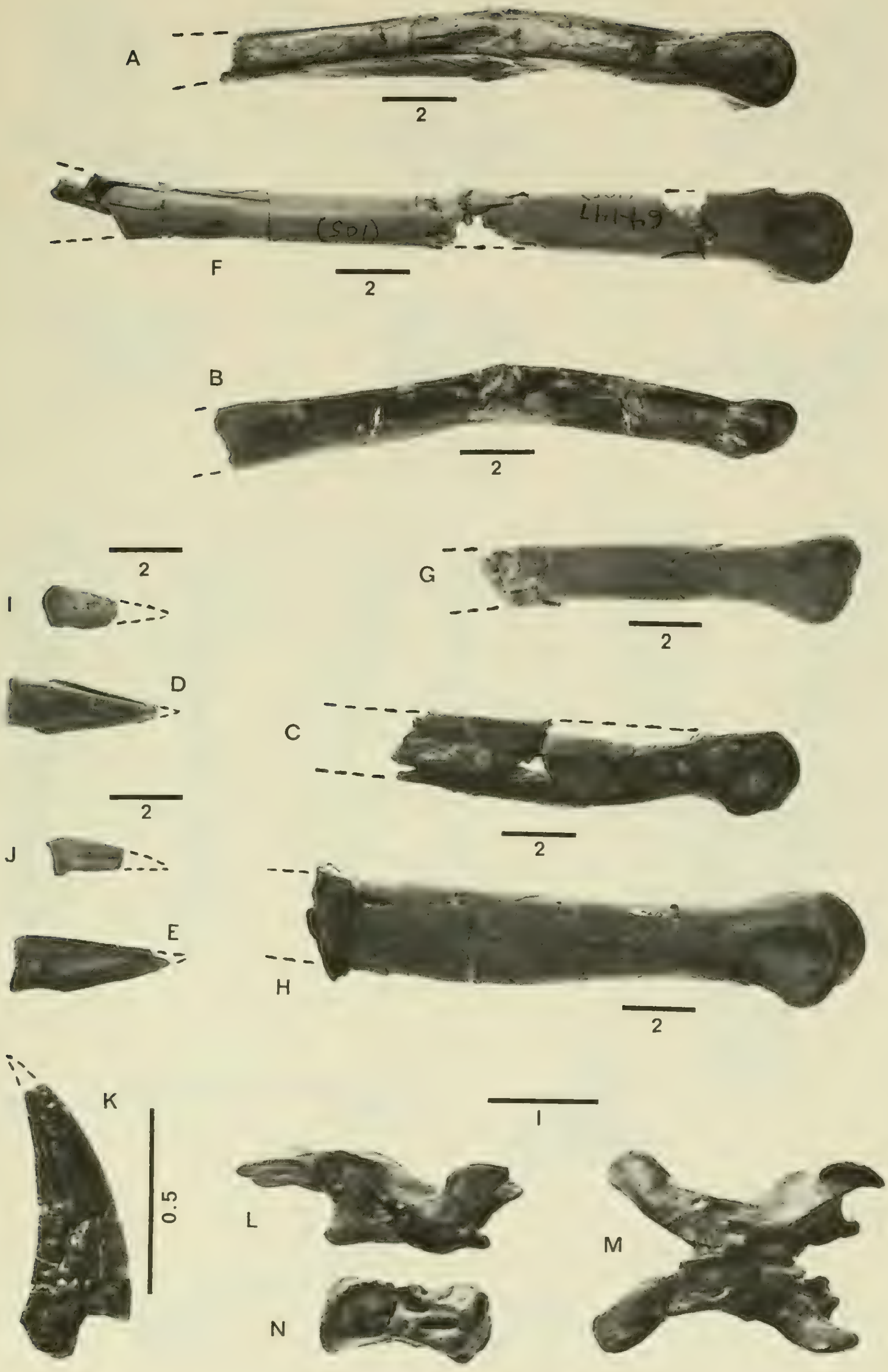

A
2
F
2
B
2
2
G
2
I
D
C
2
2
J
E
H
2
K
0.5
1
L
M
N

PLATE 12

A and B) Anterior dorsal neural arch, type, *Microvenator celer* (AMNH 3041) in lateral and dorsal views; C) mid-dorsal neural arch, type, *Microvenator celer* (AMNH 3041), in dorsal view; D and E) dorsal centrum, type, *Microvenator celer* (AMNH 3041) in lateral and axial view; F) posterior dorsal neural arch, type, *Microvenator celer* (AMNH 3041) in later view; G and H) left humerus, type of *Microvenator celer* (AMNH 3041) in lateral and anterior views; I and J) left ulna, type of *Microvenator celer* (AMNH 3041) in lateral and anterior views; K) pubes, type of *Microvenator celer* (AMNH 3041) in anterior view; L) left radius, type of *Microvenator celer* (AMNH 3041) in lateral(?) view; M) left pubis, type of *Microvenator celer* (AMNH 3041) in lateral view; N) left metacarpal I, type of *Microvenator celer* (AMNH 3041) in internal view; O) second phalanx(?) digit II of left manus, type of *Microvenator celer* (AMNH 3041), in internal view; P) manus ungual, type of *Microvenator celer* (AMNH 3041). Scales indicate cm.

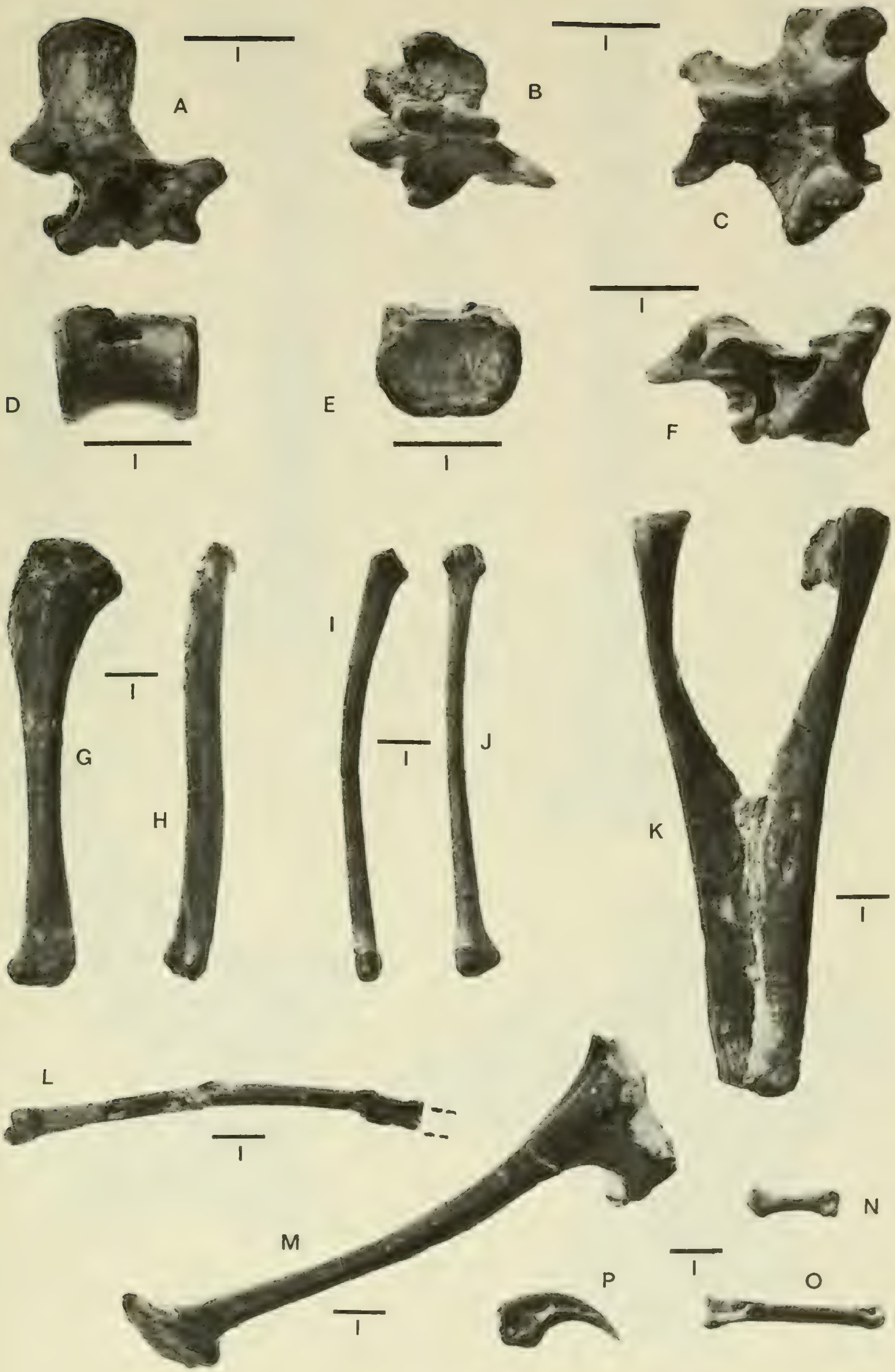

A
1
B
1
C
D
1
E
1
1
F
I
G
1
H
1
J
K
1
L
1
M
1
N
1
O
P

PLATE 13

A and B) Left femur, type of *Microvenator celer* (AMNH 3041) in external and anterior views; C) proximal end left fibula, type of *Microvenator celer* (AMNH 3041) in external view; D and E) left tibia, type of *Microvenator celer* (AMNH 3041) in anterior and external views; F) posterior dorsal vertebra of indeterminate sauropod (YPM 5449) in lateral view; G) anterior dorsal vertebra of indeterminate sauropod (YPM 5449) in posterior view. Scales indicate cm.

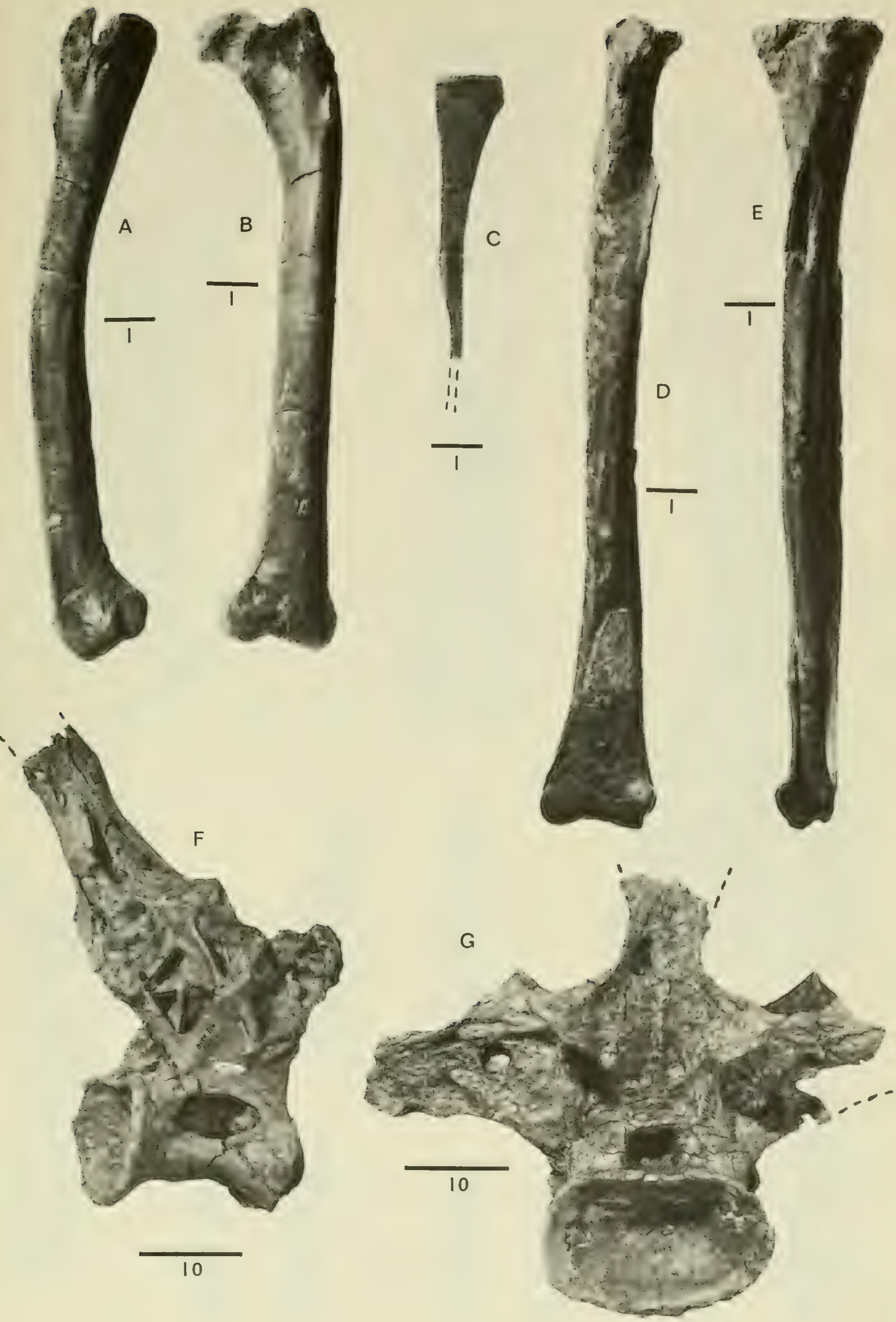

A
1
B
1
C
1
D
1
E
1
F
10
G
10

PLATE 14

A) Right humerus (YPM 5452) of indeterminate sauropod in anterior view; B) left tibia (YPM 5450) of indeterminate sauropod in posterior view; C) right femur (YPM 5451) of indeterminate sauropod in posterior view; D) left ulna (YPM 5449) of indeterminate sauropod in medial view; E) type tooth of *Astrodon johnstoni* (YPM 798) in longitudinal (left) and internal (right) views; F) tooth referred to *Pleurocoelus nanus* (USNM 6105) from the Arundel Formation, Md., in longitudinal (left) and medial (right) views; G) *Pleurocoelus*-like tooth (YPM 5375) from the Cloverly Formation in longitudinal (left) and medial (right) views; H) *Astrodon*-like tooth (YPM 5374) from the Cloverly Formation in longitudinal (left) and medial (right) views. Scales indicate cm.

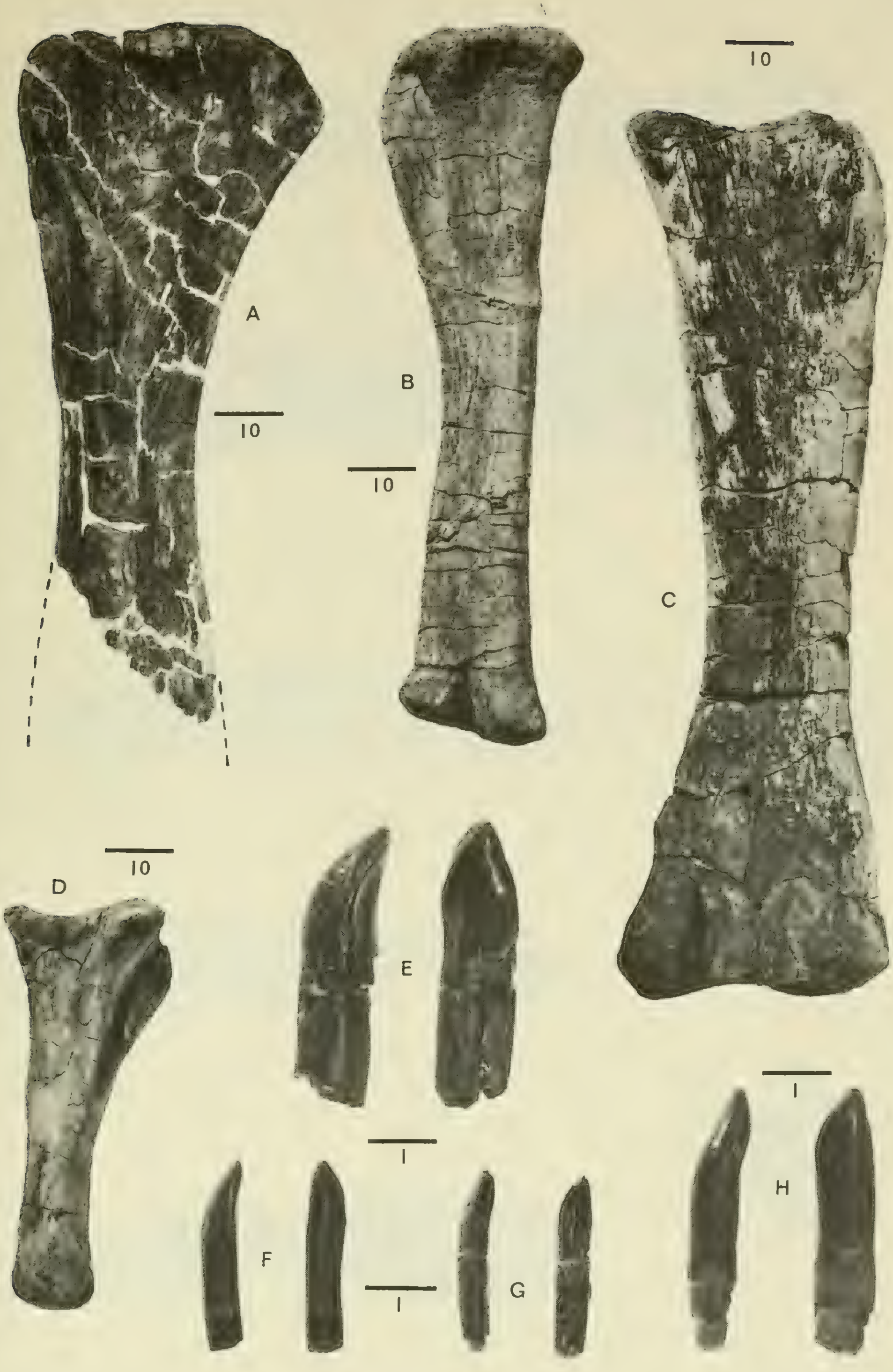

10
A
10
B
10
C
10
D
E
1
F
1
G
1
H

PLATE 15

A and B) Probable sauropod cervical centrum (YPM 5294) in lateral and dorsal views; C, D and E) indeterminate amioid dentary (left) (YPM 5519) in dorsal, medial and lateral views; F) *Camptosaurus dispar* dentary tooth (YPM 1877, type) in medial view; G) *Camptosaurus dispar* maxillary tooth (YPM 1877, type) in lateral view. Scales indicate cm.

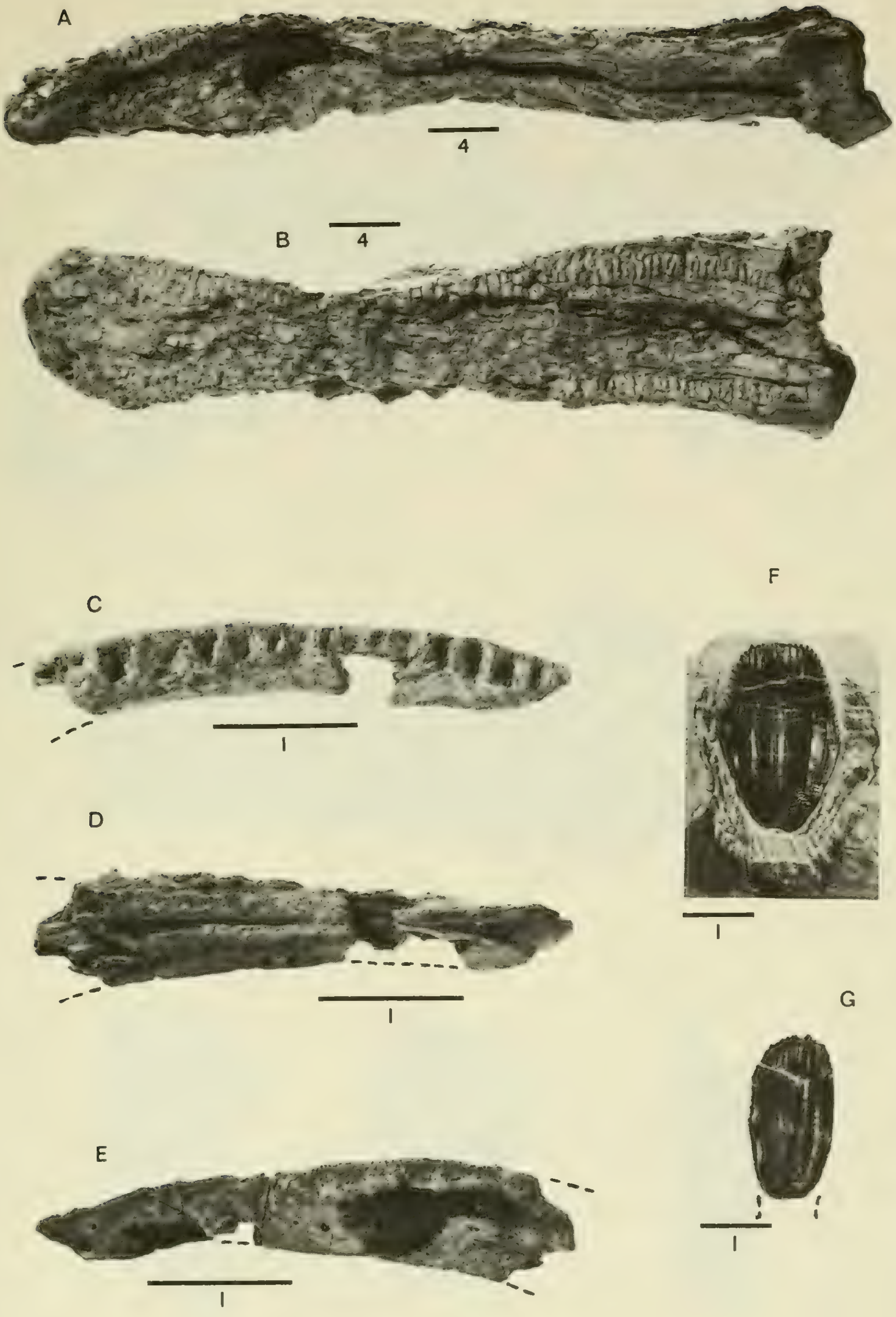

A
4
B
4
C
1
F
1
D
1
G
1
E
1

PLATE 16

A) Skull of *Tenontosaurus tilletti* (YPM 5456) in left lateral view; B) left mandible of *Tenontosaurus tilletti* (YPM 5456); C and D) maxillary teeth of *Tenontosaurus tilletti* (YPM 5456) in lateral view; E) right maxillary tooth of *Tenontosaurus tilletti* (YPM 5456) in anterior view. Scales indicate cm.

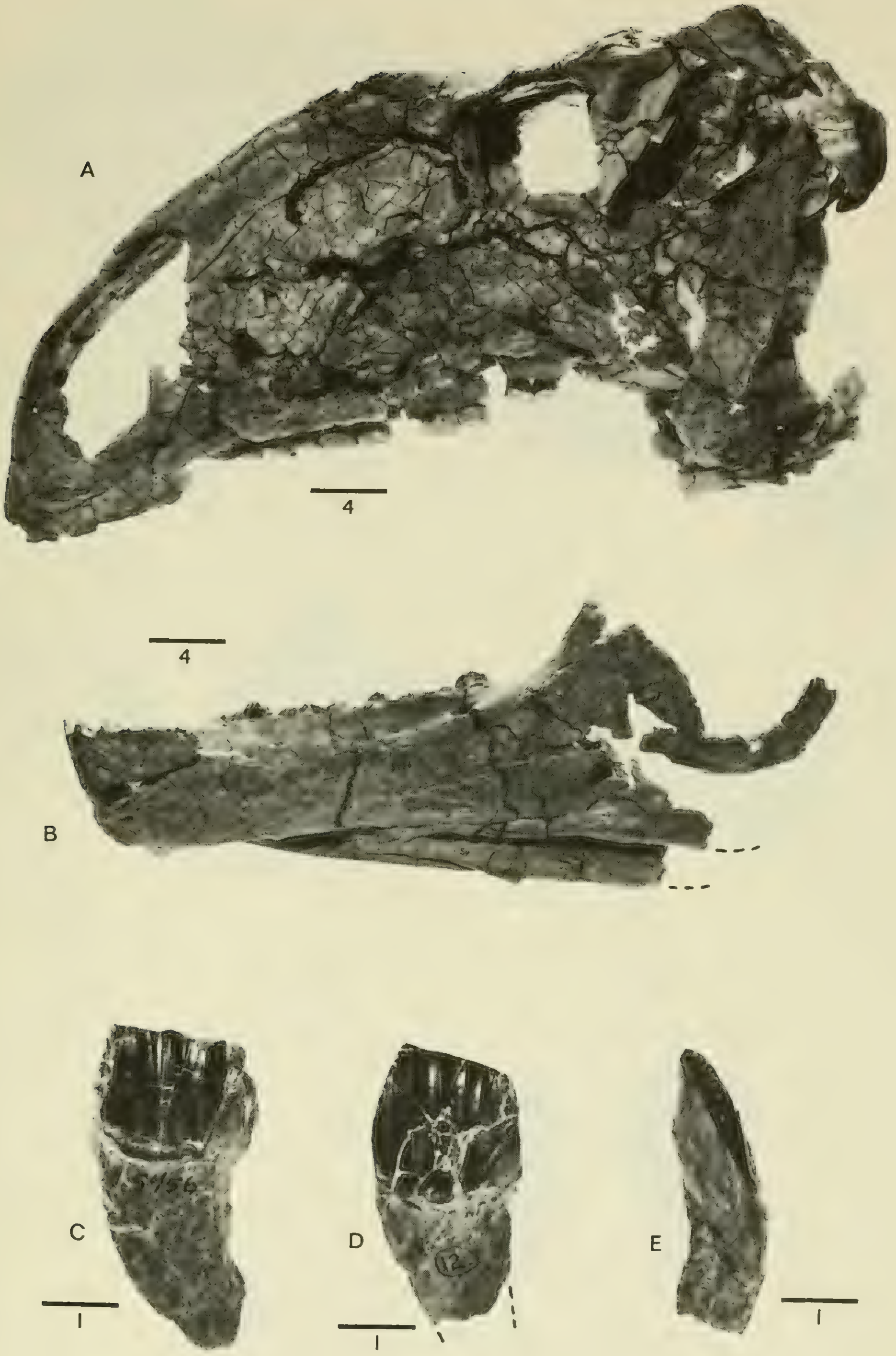

A
4
4
B
C
D
12
E
1
1
1

PLATE 17

Skull (A) of *Tenontosaurus tilletti* (YPM 5456) in right lateral view; B) right mandible of *Tenontosaurus tilletti* (YPM 5456); C) right dentary tooth of *Tenontosaurus tilletti* (YPM 5456) in anterior view; D and E) worn and unworn dentary teeth of *Tenontosaurus tilletti* (YPM 5456), in medial view. Scales indicate cm.

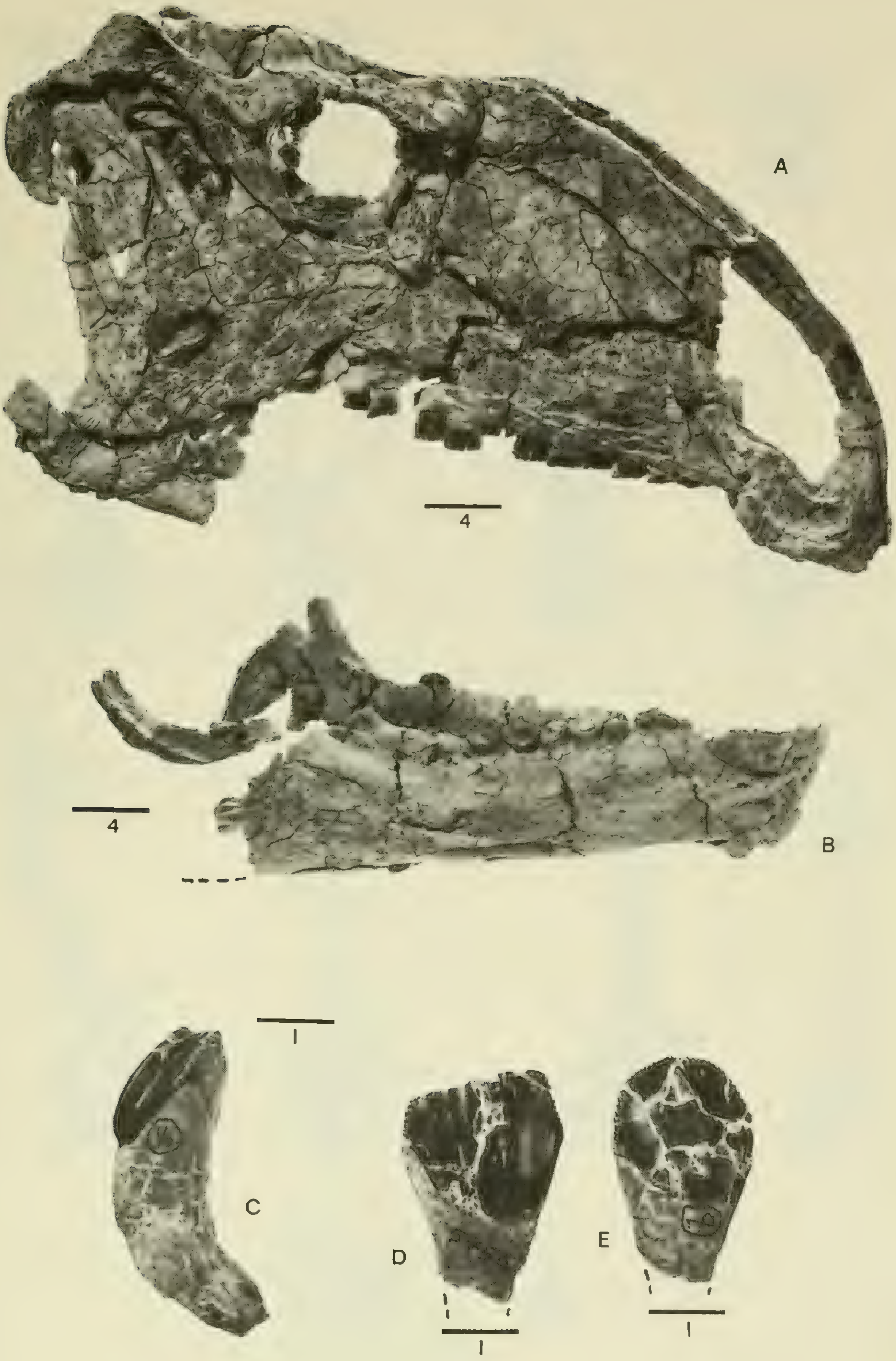

A
4
4
B
1
C
D
1
E
1

PLATE 18

A) Axis and odontoid of *Tenontosaurus tilletti* (YPM 5456) in lateral view; B) same in posterior view; C) cervical vertebra of *Tenontosaurus tilletti* (YPM 5456) in lateral view; D) same in posterior view; E) 5th dorsal vertebra of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; F) same in posterior view; G) 14th dorsal vertebra of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; H) same in posterior view; I) 5th caudal vertebra of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; J) same in posterior view; K) 12th caudal vertebra of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; L) same in posterior view; M) 32nd caudal vertebra of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; N) same in posterior view. Scale indicate cm.

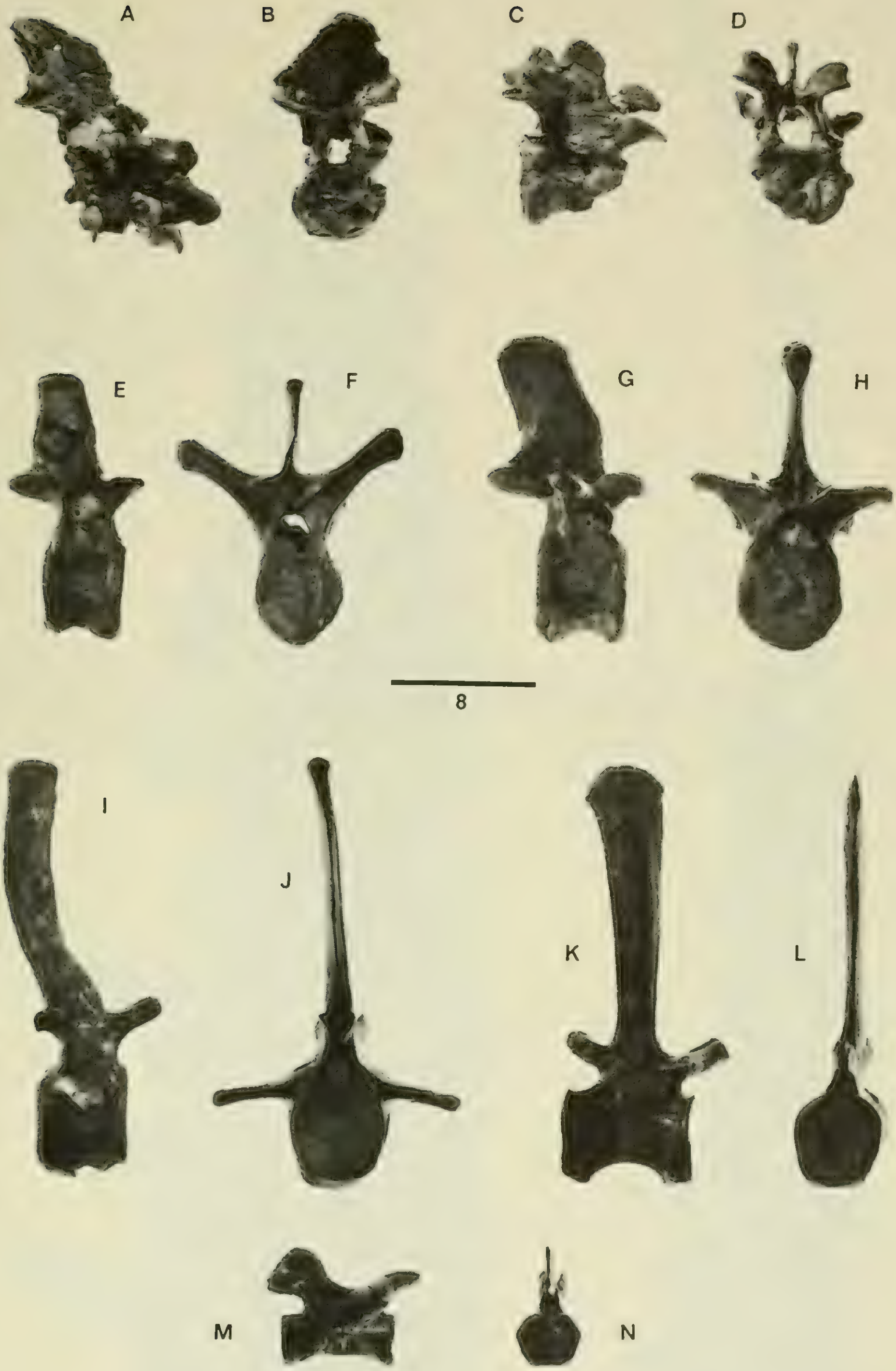

A
B
C
D
E
F
G
H
8
I
J
K
L
M
N

PLATE 19

A) Partial caudal series (Nos. 20 to 42) of *Tenontosaurus tilletti* (AMNH 3034) with ossified hypaxial and epaxial tendons in place; B) proximal half of same, enlarged to show details of ossified tendons. (Photographs courtesy of American Museum of Natural History.) Scales indicate cm.

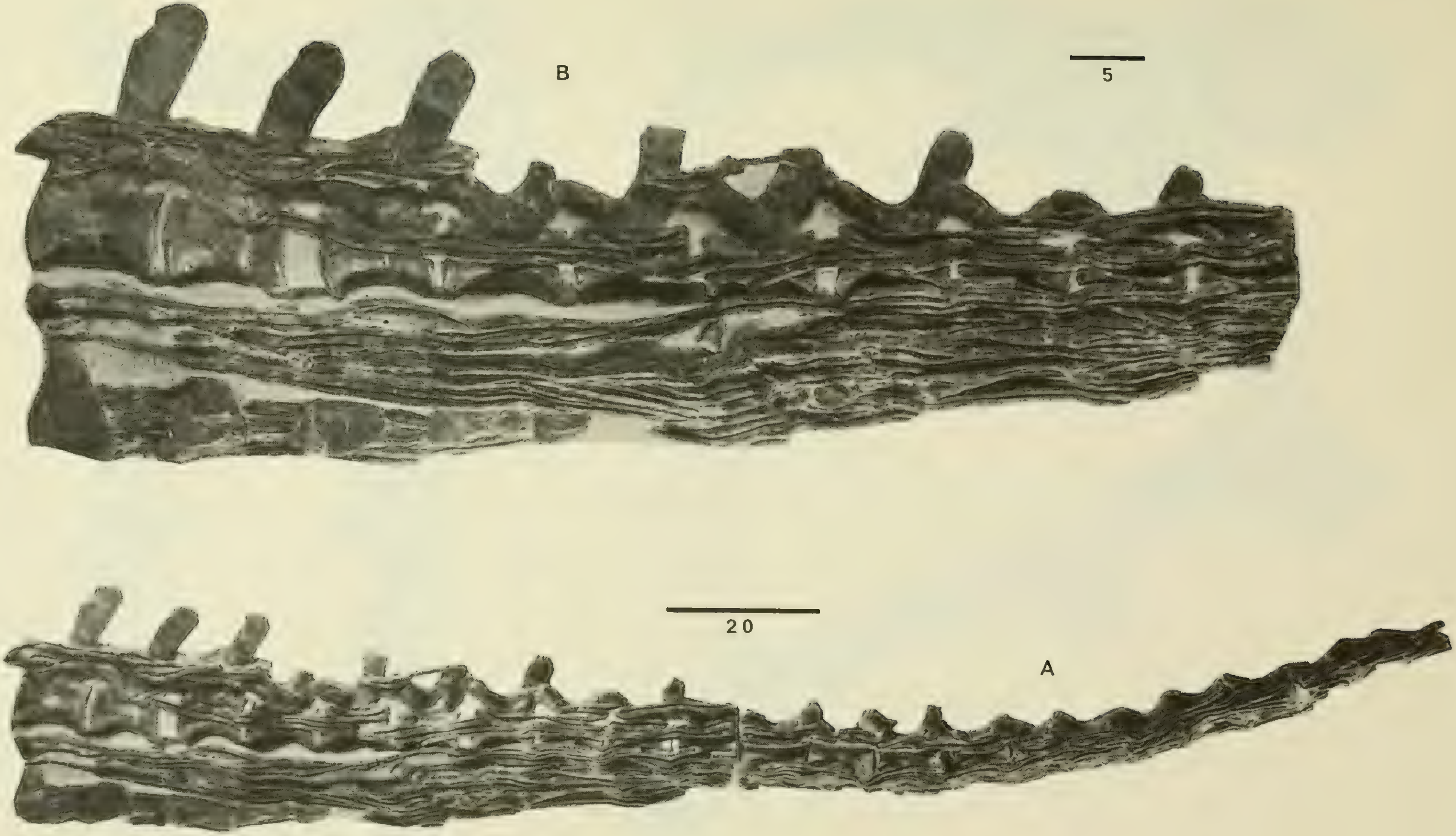

B
5
20
A

PLATE 20

A) Left pubis of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; B) left ilium of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; C) right ischium of *Tenontosaurus tilletti* (AMNH 3040) in lateral view; D and E) right femur of *Tenontosaurus tilletti* (PU 16338) in posterior and internal views. Scale indicates cm.

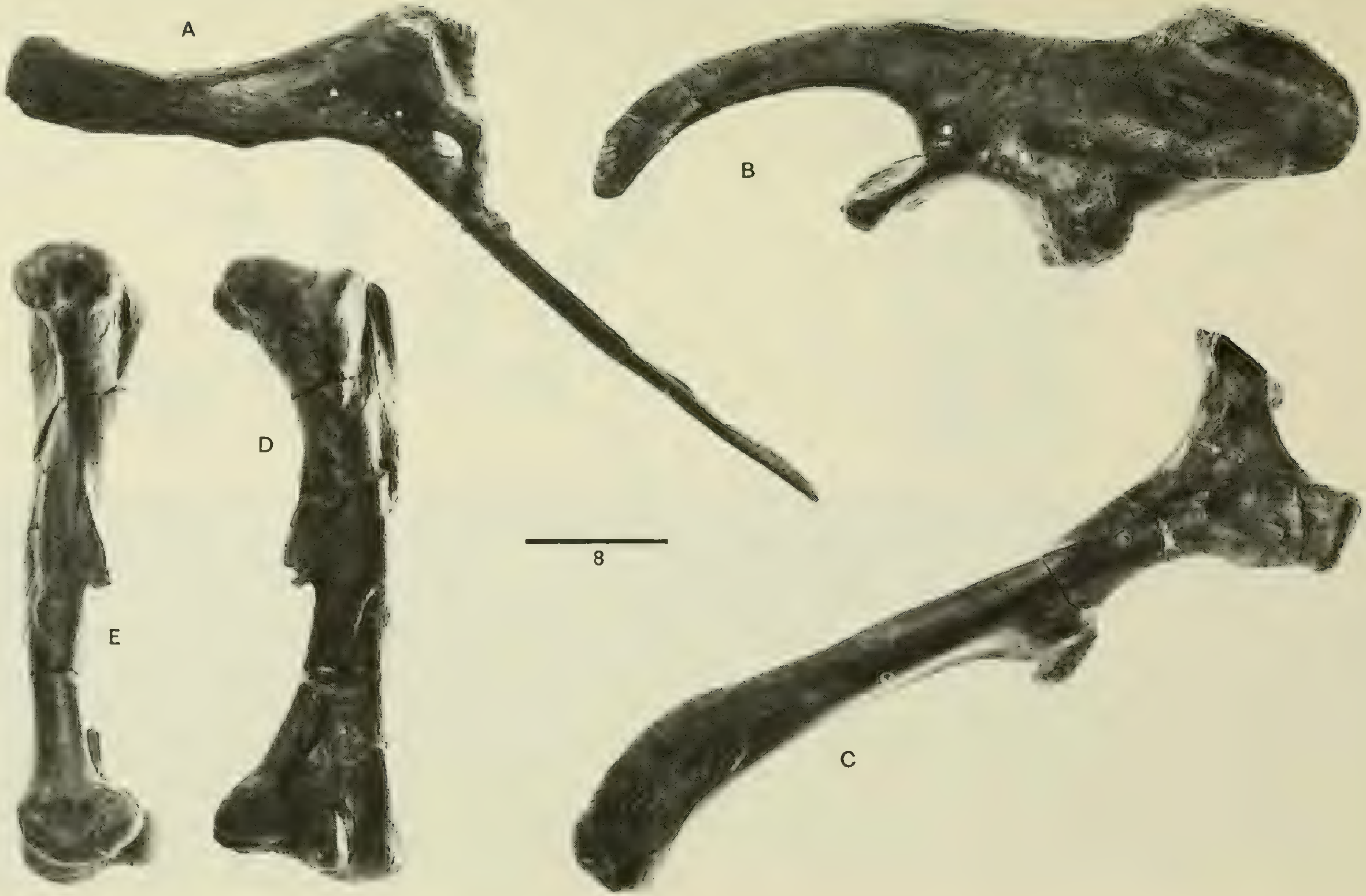

A
B
D
8
E
C

PLATE 21

A) Left manus of *Tenontosaurus tilletti* (OU 11) in dorsal view; B) left pes of *Tenontosaurus tilletti* (PU 16338) in dorsal view; C) mounted skeleton of *Tenontosaurus tilletti* (AMNH 3034). Scales indicate cm.

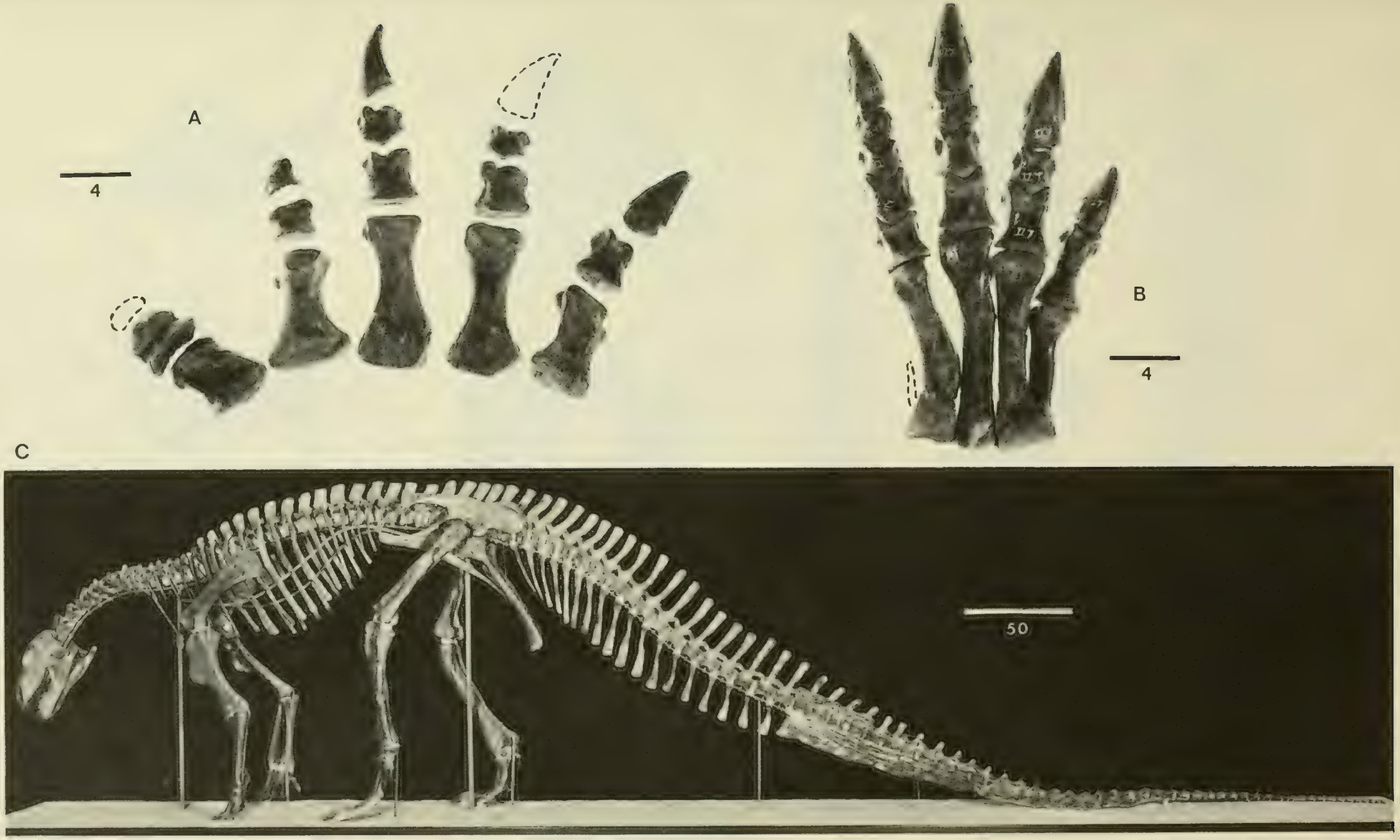

A
4
B
4
C
50

PLATE 22

A) Right mandible of *Sauropelta edwardsi* (YPM 5502) in external view; B) same in medial view; C) same in dorsal view; D, E, and F) isolated teeth of *Sauropelta edwardsi* (YPM 5526, 5525 and 5350) in transverse (labial or lingual?) above, and longitudinal (anterior or posterior?) below; G) axis and odontoid of *Sauropelta edwardsi* (AMNH 3035) in lateral view; H) same in posterior view; I) posterior cervical of *Sauropelta edwardsi* (AMNH 3035) in lateral view; J) same in anterior view; K) a posterior dorsal vertebra (12th?) of *Sauropelta edwardsi* (AMNH 3032, type) in lateral view. Scales indicate cm.

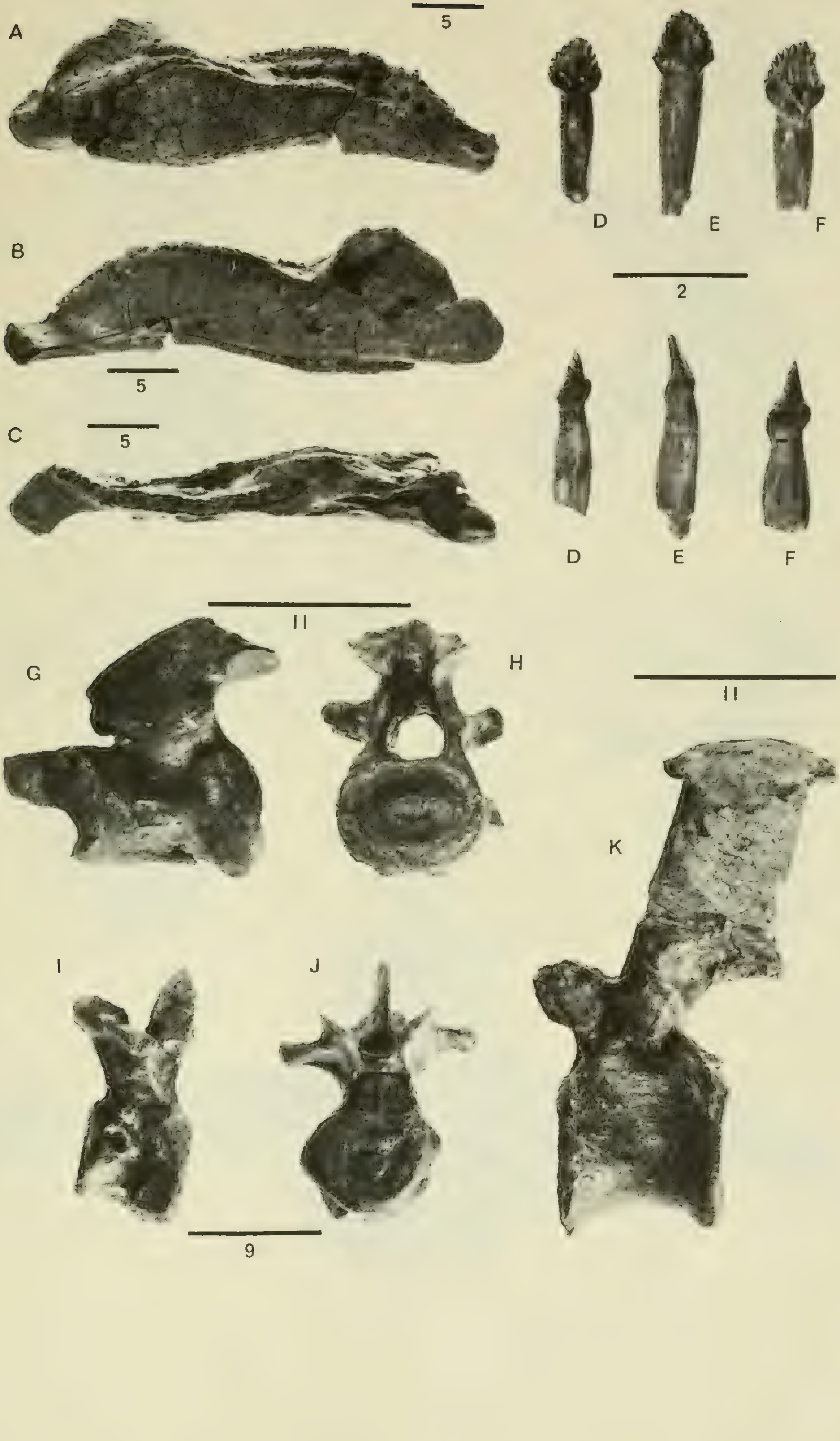

5
A
D
E
F
B
5
2
C
5
D
E
F
11
G
H
11
K
I
J
9

PLATE 23

A) Posterior dorsal vertebra (12th?) of *Sauropelta edwardsi* (AMNH 3032, type) in posterior view (same as Plate 22K); B) anterior caudal vertebra of *Sauropelta edwardsi* (AMNH 3032, type) in lateral view; C) same in anterior view; D) distal caudal vertebra of *Sauropelta edwardsi* (AMNH 3032, type) in lateral view; E) same in posterior view. Scales indicate cm.

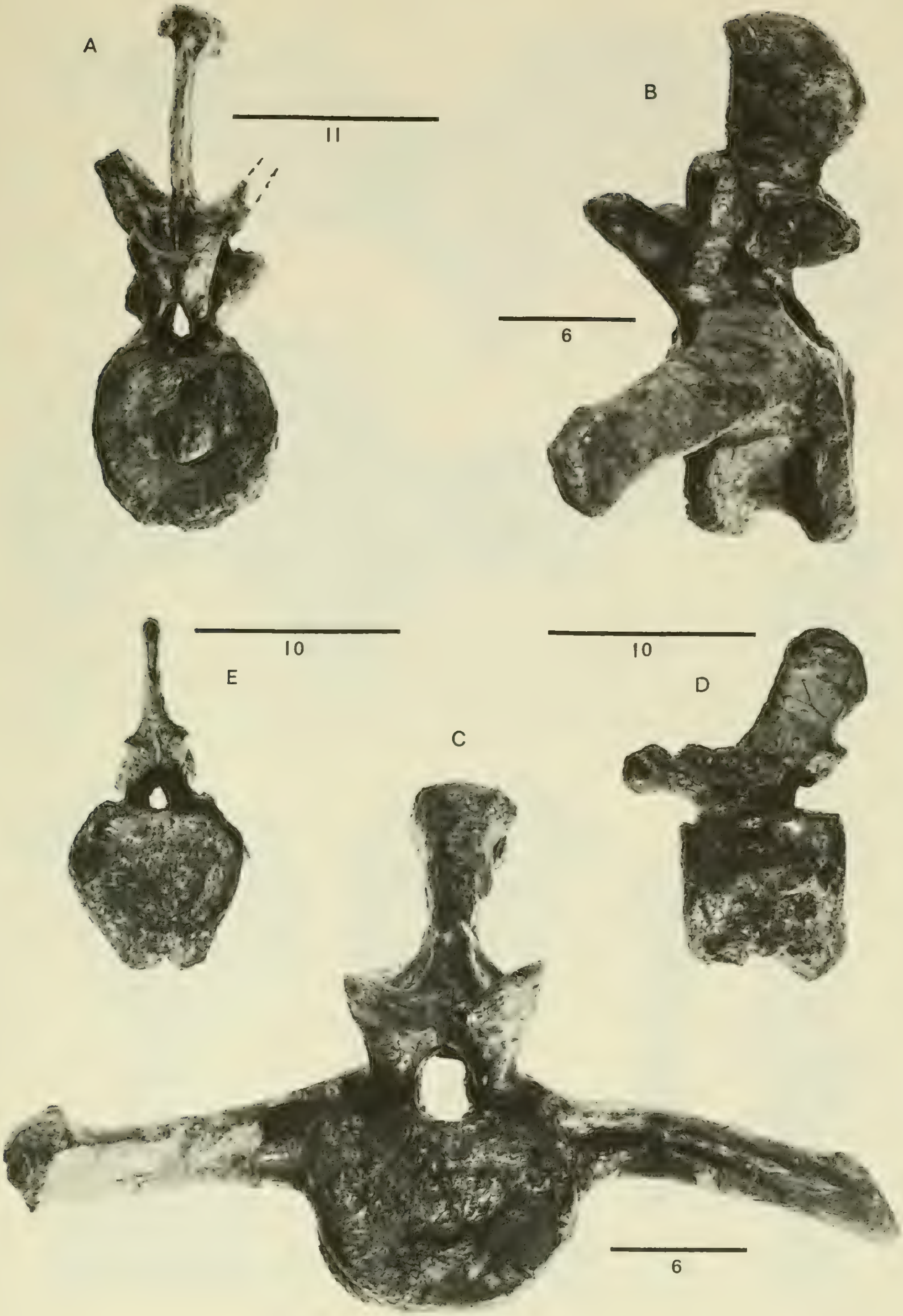

A
11
B
6
10
E
10
D
C
6

PLATE 24

A) Left scapulocoracoid of *Sauropelta edwardsi* (YPM 5179) in medial view; B) same in lateral view; C and D) right humerus of *Sauropelta edwardsi* (AMNH 3032, type) in posterior and anterior views; E and F) left ulna of *Sauropelta edwardsi* (AMNH 3032, type) in posterior and internal views; G) left radius of *Sauropelta edwardsi* (AMNH 3032, type) in internal view. Scales indicate cm.

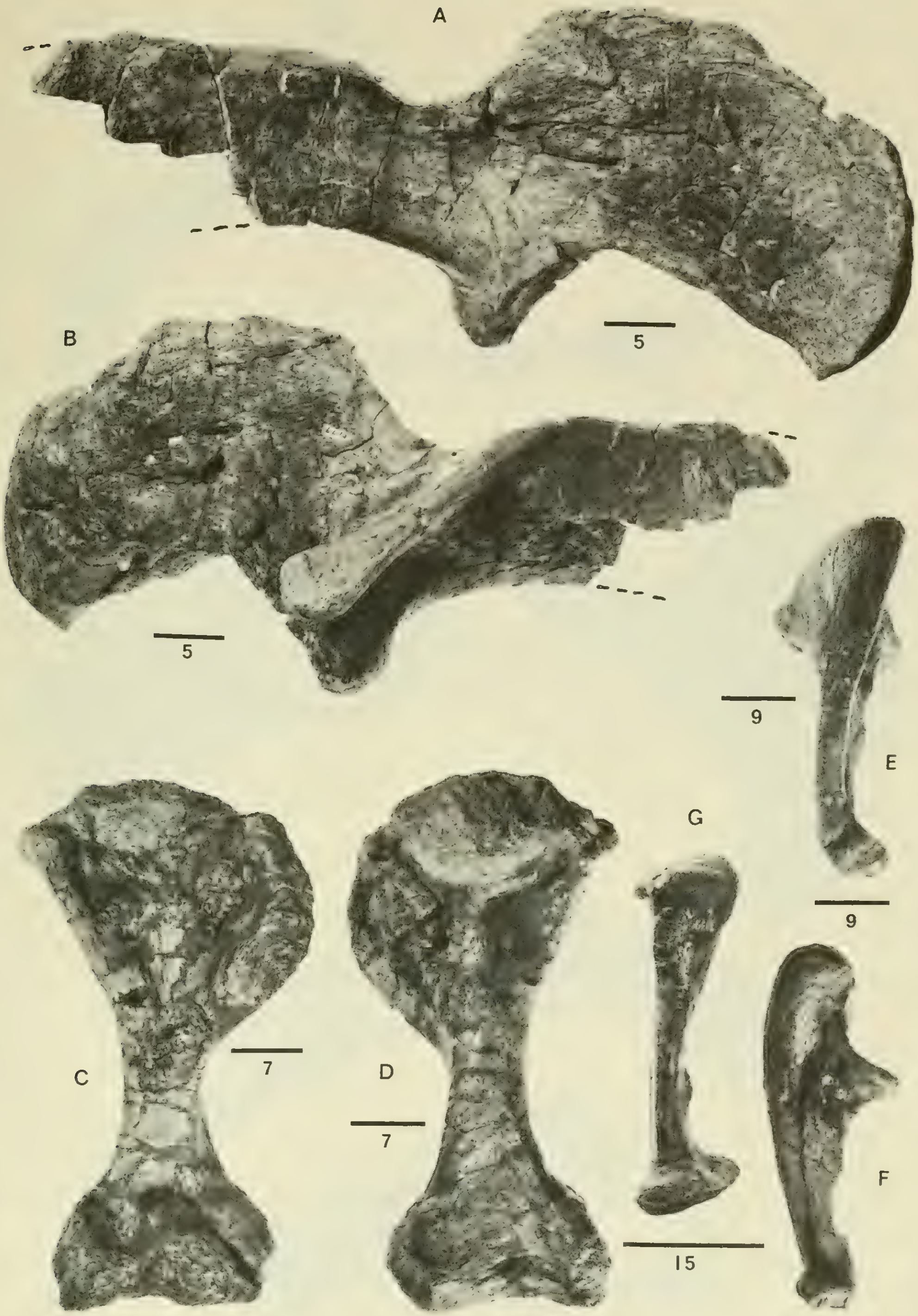

A
5
B
5
9
E
9
G
C
7
D
7
15
F

PLATE 25

A) Left ischium of *Sauropelta edwardsi* (AMNH 3032, type) in medial view; B) same in external view; C) same in dorsal view; D) right pubis of *Sauropelta edwardsi* (YPM 5141) in medial view; E) same in external view; F) same in dorsal view; G) right ischium and pubis of *Sauropelta edwardsi* (YPM 5141) in articulation. Scales indicate cm.

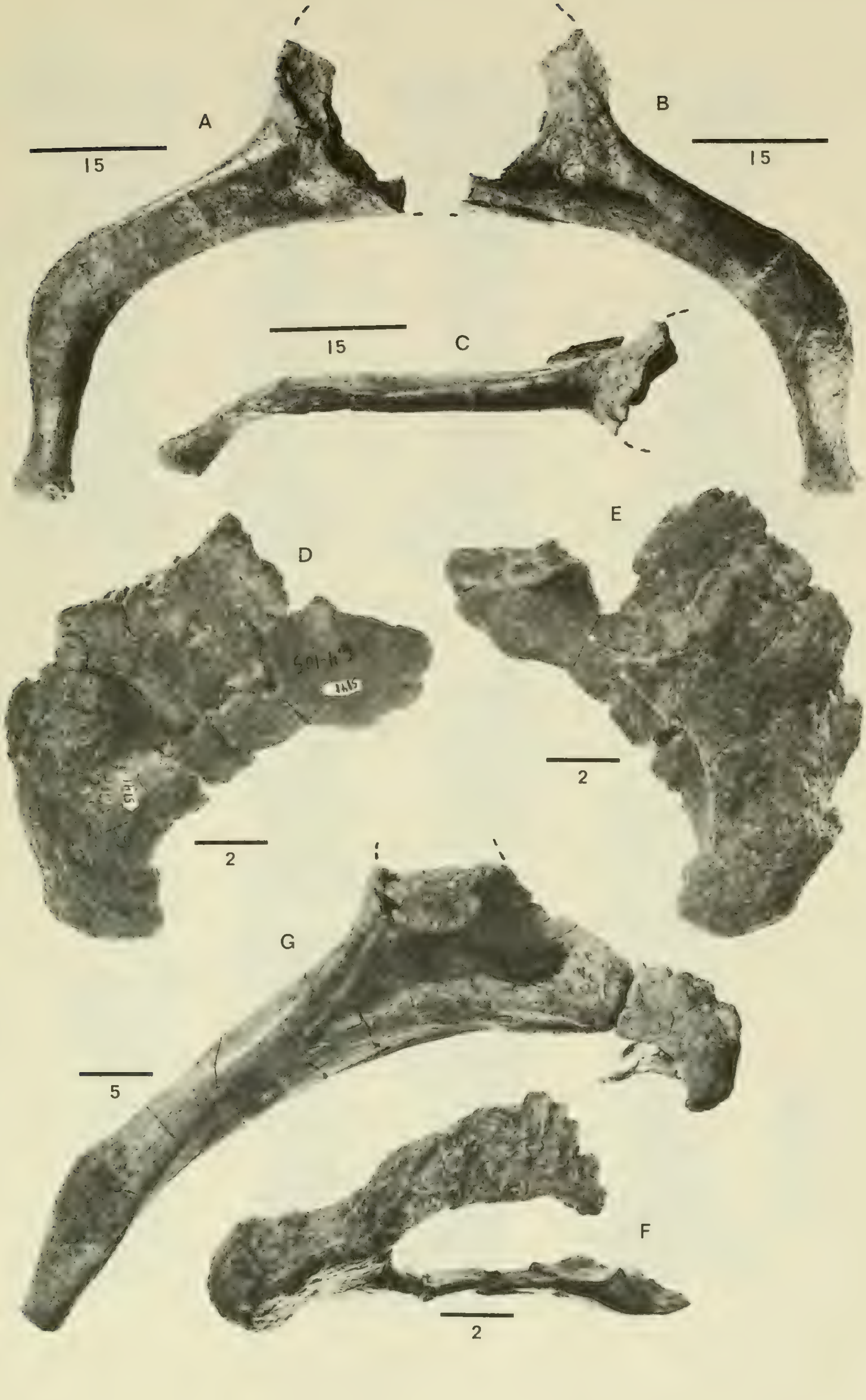

A
15
B
15
C
15
D
E
2
2
G
5
F
2

PLATE 26

A and B) Right femur of *Sauropelta edwardsi* (AMNH 3032, type) in posterior and medial views; C and D) left tibia of *Sauropelta edwardsi* (AMNH 3032, type) in lateral and posterior views; E) right pes of *Sauropelta edwardsi* (AMNH 3032, type) in dorsal view. Scales indicate cm.

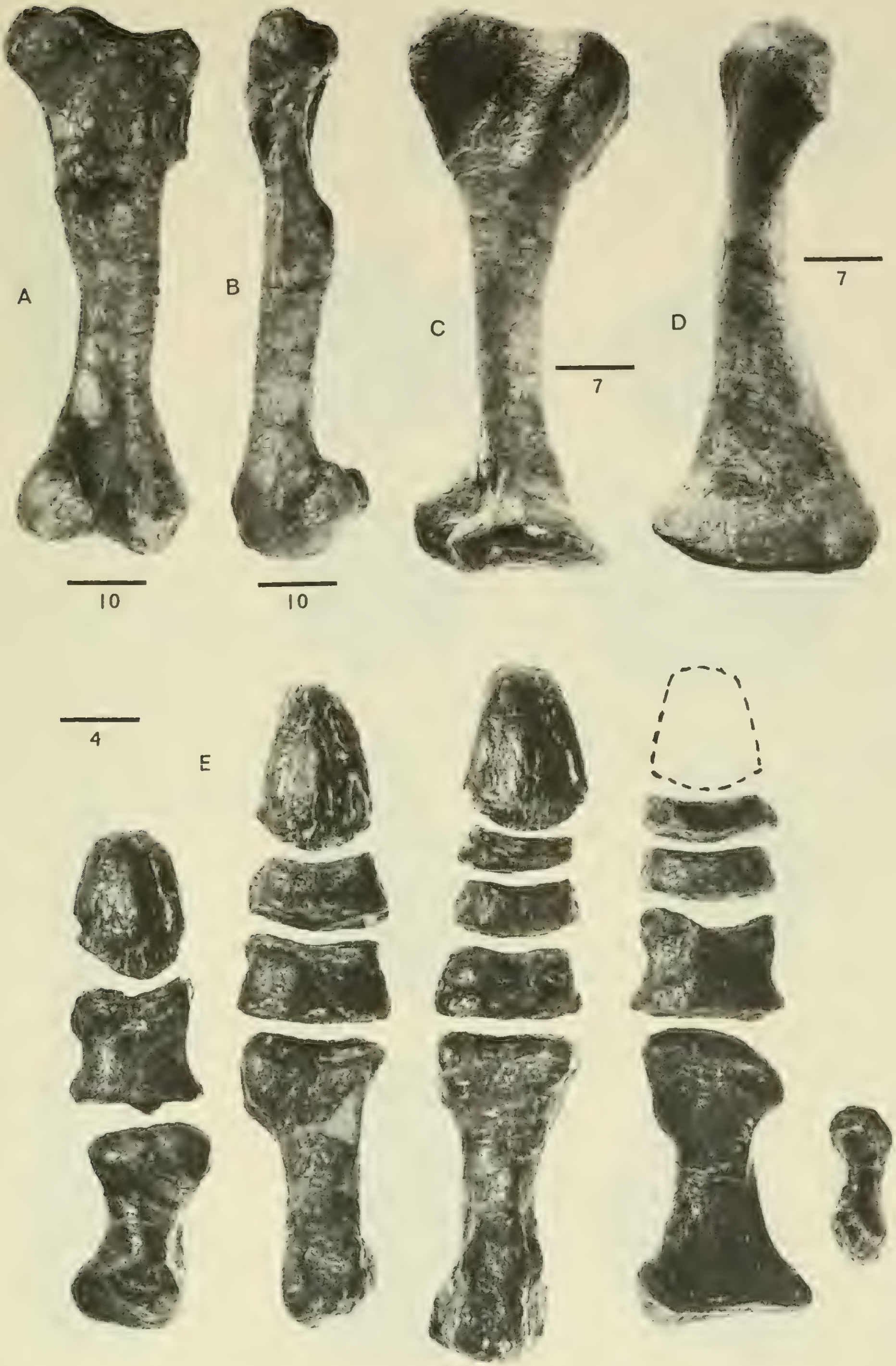
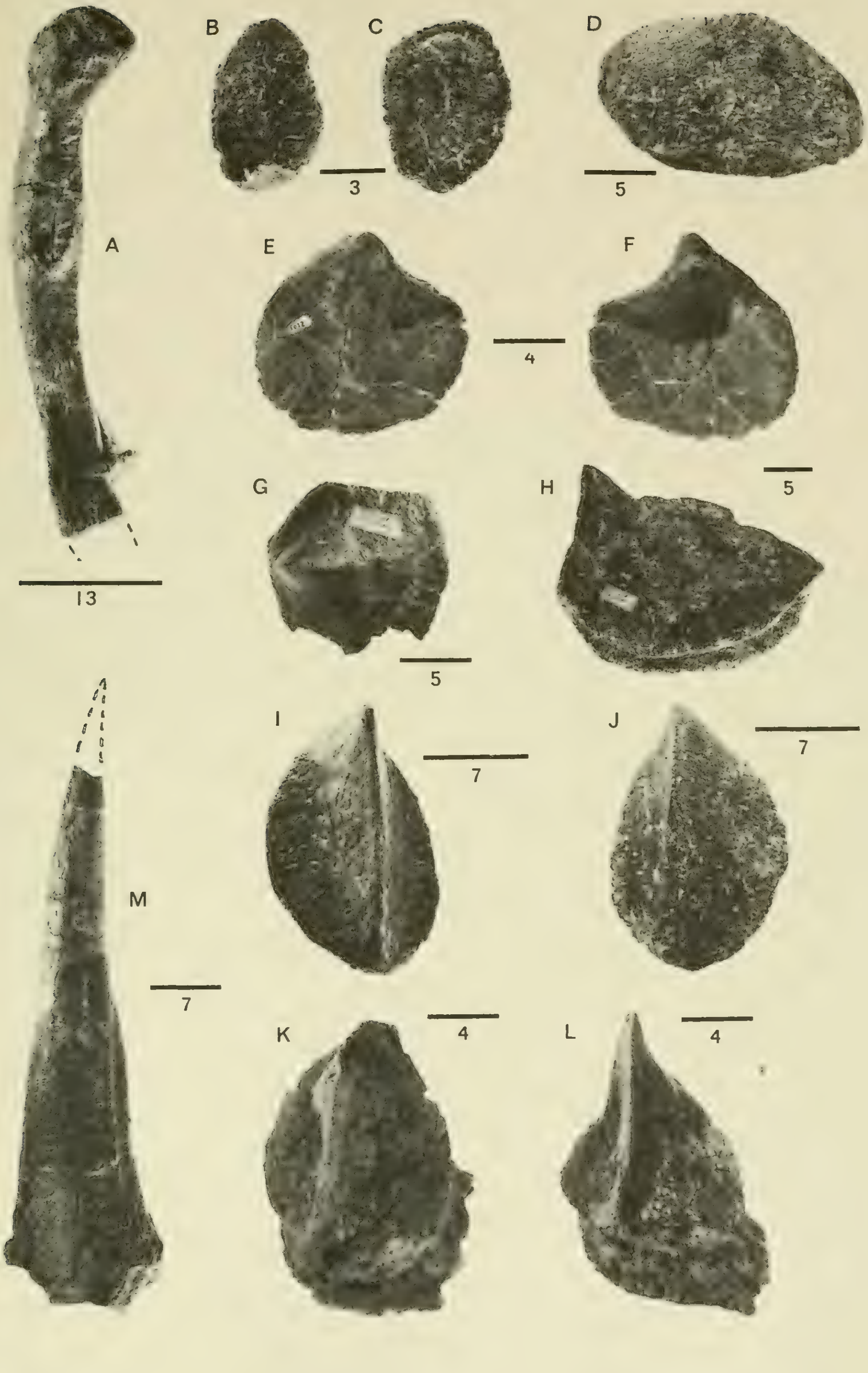

A
10
B
10
C
7
D
7
4
E

PLATE 27

A) Proximal half of left fibula(?) of *Sauropelta edwardsi* (AMNH 3032, type) in medial(?) view; B through L) various types of dermal plates of *Sauropelta edwardsi*, ranging from flat or slightly convex (B, C and D), slightly peaked (E, dorsal and F ventral views), moderately peaked (G), narrow blades (H), moderately keeled or ridged (I and J), to sharply ridged (K, dorsal view and L, longitudinal view); M) a long cylindrical spine, presumably from the shoulder region. B, C, and D) = (AMNH 3035); E and F) = (YPM 5072); G and H) = (AMNH 3032, type); I and J) = (AMNH 3032, type); K and L) = (YPM 5082); M) = AMNH 3032, type). Scales indicate cm.


A
B
C
3
D
5
E
F
4
5
13
G
H
5
I
J
7
7
M
7
K
L
4
4

I–A ALKALI CREEK* CLOVERLY POST OFFICE** Darton, 1906 and Fisher, 1906		This Report		I–B SHELL CREEK DOME Darton, 1906		This Report		SHELL Hewett and	
10′ 10′	Light buff sandstone. Tan sandstone.	VIII		15′	Massive brown sandstone.	VIII		25′	“Greybu
4′ 10′ 10′ 20′ 3′ 12′ 3′ 20′	Maroon clay. Red and tan sandy clay. Drab sandy clay. Deep maroon sandy clay. Hard tan sandstone. Deep maroon & purple variegated clay. Maroon sandstone Deep maroon sandy clay.	VII	CLOVERLY FORMATION	20′ 20′	Soft gray sandstone (sandy clay). Soft deep brown sandstone (sandy clay).	VII	CLOVERLY FORMATION	75′	Variega
11′	Olive-green sandstone.	VI		15′	Olive-green sandstone.	VI			Sandsto
50′ 15′ 5′ 10′ 10′ 45′	Pale-green massive shale. Gray sandstone. Pale-green massive shale. Blue-black shale. Maroon massive shale. Variegated massive shale.	V			MORRISON FORMATION (Not described)	V		↓	Variega sands
		IV				IV		↓	
6′ 65′ 6′ 85′	Thin-bedded gray sandstone. Variegated massive shale. Pale-green to white sandstone. Pale-green and maroon shale.	III	MORRISON FORMATION			III	MORRISON FORMATION	↓	
45′	Pale-green massive sandstone.	II(?)				II		↓	
40′	Red sandy shale.	I				I		200′ to 300′	

I-A ALKALI CREEK* CLOVERLY POST OFFICE**			I-B SHELL CREEK DOME			I-C SHELL CREEK DOME			I-D CLOVERLY POST OFFICE	
Darton, 1906 and Fisher, 1906	This Report		Darton, 1906	This Report		Hewett and Lupton, 1917	This Report		Lee, 1927	This Report
10' Light buff sandstone. 10' Tan sandstone.	VIII		15' Massive brown sandstone.	VIII		25' "Greybull sandstone".	VIII		25' "Greybull sandstone".	VIII
4' Maroon clay. 10' Red and tan sandy clay. 10' Drab sandy clay. 20' Deep maroon sandy clay. 3' Hard tan sandstone. 12' Deep maroon & purple variegated clay. 3' Maroon sandstone 20' Deep maroon sandy clay.	VII	CLOVERLY FORMATION	20' Soft gray sandstone (sandy clay). 20' Soft deep brown sandstone (sandy clay).	VII	CLOVERLY FORMATION	75' Variegated shale.	VII	CLOVERLY FORMATION	45' Variegated clay. 10' Sandstone. 50' Variegated clay.	VII
11' Olive-green sandstone.	VI		15' Olive-green sandstone.	VI		Sandstone.	VI		35' Light-colored pebbly sandstone.	VI
[illegible] Pale green massive shale. 15' Gray sandstone 5' Pale-green massive shale 10' Blue-black shale. 10' Maroon massive shale. 45' Variegated massive shale.	V		MORRISON FORMATION (Not described)	V		↓ Variegated shale and sandstone.	V		?' Dark shale	V
	IV			IV		↓ "	IV			IV
6' Thin-bedded gray sandstone [illegible] Variegated massive shale. 6' Pale-green to white sandstone. 85' Pale-green and maroon shale.	III	MORRISON FORMATION		III	MORRISON FORMATION	↓ "	III	MORRISON FORMATION	" (?)	III
[illegible] Pale-green massive sandstone	II(?)			II		↓ "	II			II
[illegible] Red sandy shale	I			I		200' to 300' "	I			I

I-E SHEEP MOUNTAIN 8 Miles NW of Greybull			I-F KANE, WYOMING			I-G POTATO RIDGE — CHERRY ANTICLINE Sec. 3 & 10, T.51 N., R.91 W.			I-H KANE* and HIMES,** WYOMING	
	Lee, 1927	This Report		Lee, 1927	This Report		Pierce, 1948	This Report		Moberly, 1960	This Report
	100' Sandstone.	+ VIII		75' Sandstone.	VIII	CLVRLY. FM.	72' (Rusty Beds) 42' Interbedded gray, yellow or red shale and yellow, pink or gray thin-bedded, fine-grained ss.	+ VIII	SYKES MT. FM.	— Sandstone, siltstone and shale.	VIII
CLOVERLY FORMATION	95' Highly colored clay.	VII	CLOVERLY FORMATION	— ↓ Red shale.	VII		43' Silty, clayey shale, palely variegated gray, red and purplish, — (See Unit VI below)	VII		** 4' Sandy mudstone. 13' Gray and brown claystone. 15' Channel sandstone. 6' Yellow-gray claystone 4' Green-gray sandstone 14' Sandstone, gray and red. 2' Sandstone, dark red.	VII
		VI			VI		2' 2-foot bed of fine gray ss. at base.	VI	CLOVERLY FORMATION	** 6' Soft, yellow sandstone. 28' Sandstone, greenish-yellow.	VI
	70' Gypsum. 118' Variegated clay. 20' Nodular chert.	V		150' "	V	MORRISON FORMATION	19' Bentonitic(?) gray clay. Lower part is black and waxy. 5' Gray fine-grained, tuffaceous(?) sandstone weathers to sharp angular pieces. 47' Variegated gray, red and purplish shale: lower part contains chalcedony.	V		* 36' Gray mudstone. 1' Siliceous mudstone. 84' Dark gray mudstone. 40' Mudstone, green and red-brown. 2' Siliceous mudstone. 8' Mudstone, green and red-brown. 35' Sandstone, white 12' Mudstone, green and red-brown.	V
		IV		50' Sandstone, coarse-grained, cross-bedded, massive.	IV		8' Gray and yellow sandstone, locally coarse-grained and ledge forming.	IV		18' Sandstone, quartz and black chert	IV
MORRISON FORMATION	↓ Variegated shale.	III	MORRISON FORMATION	— ↓ Variegated shale.	III		79' Gray, yellow and green bentonitic shale. 6' Soft, clayey sandstone. 76' Variegated red, gray and greenish-gray shale with thin sandstone.	III		15' Mudstone, dark red-brown	III
	"	II			II		— Variegated reddish-brown and gray shale and yellow or light gray sandstone.	II	MORRISON FORMATION		II
	240' "	I		290' " (?)	I			I			I
							SUNDANCE FORMATION				

CHART I
PUBLISHED SECTIONS:
CLOVERLY – SHELL CREEK AREA
(See Figure 2 for locations.)

I-C REEK DOME		I-D CLOVERLY POST OFFICE				I-E SHEEP MOUNT. 8 Miles NW of Gre		
upton, 1917	This Report		Lee, 1927		This Report		Lee, 1927	
ll sandstone".	VIII		25′	"Greybull sandstone".	VIII		100′	Sandstone.
ed shale.	VII	CLOVERLY FORMATION	45′ 10′ 50′	Variegated clay. Sandstone. Variegated clay.	VII	CLOVERLY FORMATION	95′	Highly colored clay
e	VI		35′	Light-colored pebbly sandstone.	VI			
ted shale and tone.	V	MORRISON FORMATION	?′	Dark shale	V		70′ 118′ 20′	Gypsum. Variegated clay. Nodular chert.
	IV				IV	MORRISON FORMATION		
	III		"	(?)	III		↓	Variegated shale.
	II				II			"
	I				I		240′	"

II–I

NORTH BIG TRAILS, WYOMING

	This Report			Mirsky, 1962a	MING	This Report
n, 1!	VIII	CLOVERLY FORMATION	4′	26. Sandstone, gray, fine, thin bedded, rusty-brown, tan and ferruginous stain.	ite, fine, y, fine, ale.	VIII
	VII		19′	25. Sandstone, white to gray, very fine, soft, rusty and lavender staining (sandy claystone?).	y-green silty,	VII
	VI		25′	24. Sandstone, white to gray, fine to coarse and conglomeratic, cross-bedded, Otter Creek Sandstone.	ite to dded. low)	VI(?)
	V					V
	IV				nses in t of	IV(?)
silty. silt. y stain. y. silty. soft. gray. green. silt. soft. soft.	III	MORRISON FORMATION	79′ 12′ 7′ 22′ 7′ 6′ 4′ 7′	23. Mudstone, pale gray-green. 22. Sandstone, gray, very fine. 21. Mudstone, dark-gray, silty. 20. Sandstone, gray, sparkly. 19. Sandstone, dark-gray. 18. Sandstone, gray, soft. 17. Sandstone, gray-green, fine. 16. Sandstone, dark-gray, very fine, soft.	olive- nted, y, very rugin- -gray, k, -green, itic, selenite. green, fine.	III(?)
	II		21′	15. Sandstone, tan, very fine to coarse, well-cemented.	fine, ginous	II(?)
	I		4′ 3′ 5′ 8′ 4′ 2′ 8′ 17′ 25′ 2′ 7′ 6′ 4′ 5′	14. Mudstone, gray, drab-gree 13. Sandstone, white, fine. 12. Sandstone, gray, olive-gree 11. Sandstone, gray, soft. 10. Sandstone, chocolate-brow 9. Sandstone, tan, soft. 8. Sandstone, gray, very fine. 7. Siltstone, dark-gray. 6. Mudstone, red-brown, greer 5. Mudstone, olive-green. 4. Sandstone, gray, soft. 3. Mudstone, gray and green. 2. Sandstone, gray, soft. 1. Sandstone, glauconitic.	gray-green ery silty. medium, sparkly. to tan, ed. gray- very gray- rown, gray-green.	I

CHART II
PUBLISHED SECTIONS: HYATTVILLE – TENSLEEP – NOWOOD CREEK AREA

(See Figure 2 for locations.)

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CHART III
PUBLISHED SECTIONS: THERMOPOLIS AREA
(See Figure 2 for locations.)

MILES OF OMING				III-F 4 MILES NORTH OF THERMOPOLIS, WYOMING		
		This report			Love, *et al.*, 1945	This Report
9' 9' 5'	G Bl) T	VIII	CLOVERLY FORMATION	3'	Lowest sandstone of Rusty Beds.	VIII
40'	V)	VII		18'	Variegated claystone.	VII
38'	L eratic.	VI		25'	Gray conglomeratic sandstone.	VI
	and- d with	V(?)		50'	Variegated claystone.	V
		IV		38'	Gray conglomeratic sandstone (sparkly quartz sandstone).	IV
59'	G	III	MORRISON FORMATION	100'	Light-green siltstone and sandstone.	III
30'	Y	II		150'	Gray sandstone.	II
	M(	I				I

CHART III
PUBLISHED SECTIONS: THERMOPOLIS AREA
(See Figure 2 for locations.)

III A — MILES NORTH OF THERMOPOLIS, WYOMING

Formation	Fisher, 1908	This Report
	9' Gray massive ss., weathers tan. 9' Blue, drab shale. 5 Thin-bedded sandstone.	VIII
	40' Variegated shale.	VII
	38' Light-colored conglomeratic, massive sandstone.	VI
		V
		IV
	59' Greenish-brown shale.	III
	30' Yellow-gray massive sandstone.	II
MORRISON FORMATION (Undescribed)		I

III B — 2 MILES NORTHWEST OF THERMOPOLIS, WYOMING

Formation	Lee, 1927	This Report
	60' Rusty-brown, ripple-marked ss.	VIII
CLOVERLY FORMATION	82' Variegated deep red shale.	VII
	42' Conglomeratic sandstone.	VI
MORRISON FORMATION (Not recorded)		V
		IV
MORRISON FORMATION		III
		II
		I

III-C — 3.5 MILES NORTH OF THERMOPOLIS, WYOMING

Formation	Lee, 1927	This Report
	53' Thin-bedded sandstone and variegated shale.	VIII
	55' Red and bluish sandy shale.	VII
CLOVERLY FORMATION	90' Conglomeratic sandstone.	VI
		V
	Conglomeratic sandstone.	IV
	— ↓ Variegated shale.	III
MORRISON FORMATION	275' Massive light-colored sandstone.	II
		I

III-D — 4.5 MILES NORTHEAST OF THERMOPOLIS, WYOMING

Formation	Lee, 1927	This Report
	(Not described) "Sandstone"	VIII
CLOVERLY FORMATION	(Not described) "Variegated shale"	VII
	75' Conglomeratic sandstone. 4' White, shaley sandstone.	VI
	20' Carbonaceous shale, lignitic.	V(?)
	25' Dark-brown chert pebble conglomerate.	IV
	— Variegated shale.	III
MORRISON FORMATION		II
		I

III-E — 10 MILES EAST OF THERMOPOLIS, WYOMING

Formation	Lee, 1927	This report
	(Not recorded)	VIII
CLOVERLY FORMATION	(Not recorded)	VII
	25' Sandstone, conglomeratic.	VI
	10' Fine-grained white sandstone, light-colored shale. 1.3' Carbonaceous clay. 0.5' Coal, impure. 1.0' Carbonaceous shale with coal. 2.7' Coal, impure. — Dark shale.	V(?)
		IV
	Variegated shale.	III
MORRISON FORMATION		II
		I

III-F — 4 MILES NORTH OF THERMOPOLIS, WYOMING

Formation	Love, *et al.*, 1945	This Report
	3' Lowest sandstone of Rusty Beds.	VIII
	18' Variegated claystone.	VII
CLOVERLY FORMATION	25' Gray conglomeratic sandstone.	VI
	50' Variegated claystone.	V
	38' Gray conglomeratic sandstone (sparkly quartz sandstone).	IV
	100' Light-green siltstone and sandstone.	III
MORRISON FORMATION	150' Gray sandstone	II
		I

IV–A

SOUTH OF CODY, WYOMING

Fisher, 1906		This Report	
?′	Sandstone.	VIII	CLOVERLY FORMATION
?′	Highly colored clay.	VII	
		VI	
?′ ?′	“Middle band of dark shale”. Highly colored clay.	V	
		IV	
		III	?
50′	Coarse-grained, pebbly ss.	II	MORRISON FORMATION
	(Not recorded.)	I	

CHART IV
PUBLISHED SECTIONS: CODY AREA
(See Figure 2 for locations.)

IV–A SOUTH OF CODY, WYOMING

Fisher, 1906	This Report
Sandstone.	VIII
Highly colored clay.	VII
	VI
"Middle band of dark shale". Highly colored clay.	V
	IV
	III
Coarse-grained, pebbly ss.	II
(Not recorded.)	I

IV–B SOUTH OF CLARK FORK CANYON

		Fisher, 1906	This Report
CLOVERLY FORMATION		(Not recorded.)	VIII
		(Not recorded.)	VII
		" "	VI
		" "	V
		" "	IV
?		" "	III
MORRISON FORMATION	80′	Massive, greenish-gray sandstone.	II
	60′ 1′	Greenish clay. Dark-gray limestone.	I

IV–C SHOSHONE CANYON AT CODY, WYOMING

		Hewett, 1914	This Report
CLVRLY. FM.	60′ 25′ 25′	Sandstone, buff, indurated, ripple-marked and thin-bedded. Shale, gray and sandy. Sandstone, buff, massive.	+ VIII
MORRISON FORMATION	50′ 6′ 12′ 4′ 10′	Shale, maroon and gray, sandy. Sandstone, buff. Shale, gray, sandy. Sandstone, buff. Shale, gray, sandy.	VII
	8′	Sandstone, buff, cross-bedded.	VI
	50′ 6′ 44′	Clay, gray, sandy. Sandstone, buff, fine-grained, ripple-marked. Clay, dark-brown to black, saurian vertebrae, limb bones and gastroliths.	V
			IV
			III
	50′	Sand, gray, argillaceous.	II
	55′ 25′ 100′	Clay, maroon, sandy. Sandstone, white, homogeneous. Clay, gray and olive, but with three maroon bands, sandy.	I

IV–D 2 MILES SOUTH OF CODY, WYOMING

		Lee, 1927	This Report
RTY. BD. GYBUL.	110′+	Rusty-brown, ripple-marked sandstone and thin beds of shale.	+ VIII
CLOVERLY FORMATION	↓	"Colored material" prevailingly maroon with dinosaur bones, stomach stones and petrified wood.	VII (82′)
			VI
	↓	" "	V
			IV
	263′	" "	III
	?′	Light-colored, massive, cross-bedded, locally conglomeratic sandstone.	II
MORRISON FORMATION	240′	Variegated beds.	I

IV–E SHOSHONE CANYON

		Johnson, 1934	This Report
	110′	Buff sandstone, thin-bedded to massive.	+ VIII
MORRISON FORMATION AND CLOVERLY FORMATION	↓	Varicolored clays with many sandstone lenses.	VII
	↓	" "	VI
	↓	" "	V
	↓	" "	IV
	↓	" "	III
	440′	" "	II
	180′	Green sandy shale.	I

IV–F WEST LIMB, HORSE CENTER ANTICLINE

		Pierce and Andrews, 1940	This Report
	85′	Sandstone, tan, thin-bedded, shale, sandy.	VIII
CLOVERLY FORMATION	36′ 27′ 25′	Shale, red and gray. Sandstone, rusty tan and gray, thin-bedded shale, gray with coal. Shale, gray and red.	VII
	17′ 2′	Sandstone, tan, rusty, cross-bedded. Conglomerate.	VI
MORRISON FORMATION	70′ 24′ 68′	Shale, variegated, massive, purple, red and gray, nodular siliceous limestone. Sandstone, coarse; conglomerate. Shale, gray and red.	V
			IV
			III
	85′	Sandstone, light gray to tan, massive and thin-bedded, cross-bedded.	II
	77′ 47′ 17′	Shale, red, gray and light gray, sandy. Shale, gray and light gray, with sandstone. Sandstone, shaly, tan to buff, shale green with 2″ coal.	I

IV–G EAST LIMB, HORSE CENTER ANTICLINE*

		Pierce and Andrews, 1940	This Report
CLVRLY. FM.	 8′ 2′	(See note below)* Sandstone, buff, ledge-former. Sandstone, gray, alternating with gray sandy sh.	VIII
MORRISON FORMATION		(Not recorded.)	VII
		" "	VI
		" "	V
		" "	IV
		" "	III
		" "	II
		" "	I

*(Pierce and Andrews listed an additional 14 sandstone and shale units overlying these two sandstones and included them in their CLOVERLY FORMATION.)

V-A

GYPSUM CREEK

	Fisher, 1908	This Report		
?′	Sandstone, rust-colored, alternating with dark shales.	VIII		
15′	Shale, dark purplish.	VII	CLOVERLY FORMATION	1
70′	Sandstone, gray, massive, with chert pebbles.	VI		7
25′ 70′ 12′ 2′ 23′	Concealed (shale?). Shale, bluish with limestone concretions containing chert. Shale, deep maroon. Sandstone, pure white. Shale, red, sandy with gypsum.	V		10 t 15
40′ 50′	Sandstone, thin-bedded with chert pebbles. Sandstone, strong, hard, blue-gray, weathers pink and brown.	IV		4 t 5
	MORRISON FORMATION (Not recorded)	III	MORRISON FORMATION	
		II		
		I		

CHART V
PUBLISHED SECTIONS: CROOKED CREEK – GYPSUM CREEK – WARREN AREA

(See Figure 2 for locations.)

V-A GYPSUM CREEK

Formation	Fisher, 1908	This Report
CLOVERLY FORMATION	Sandstone, rust-colored, alternating with dark shales.	VIII
	Shale, dark purplish.	VII
	Sandstone, gray, massive, with chert pebbles.	VI
	Concealed (shale?). Shale, bluish with limestone concretions containing chert. Shale, deep maroon. Sandstone, pure white. Shale, red, sandy with gypsum.	V
	Sandstone, thin-bedded with chert pebbles. Sandstone, strong, hard, blue-gray, weathers pink and brown.	IV
MORRISON FORMATION	MORRISON FORMATION (Not recorded)	III
		II
		I

V-B GYPSUM CREEK

Formation	Thickness	Washburn, 1909	This Report
CLOVERLY FORMATION		(Not recorded)	VIII
	15′	Dark purplish shale.	VII
	70′	Massive gray sandstone.	VI
	100 to 150′	Bright, variegated clays and soft sandstones with concretions of limestone and chert.	V
	40 to 50′	Massive sandstone with shale partings and a thin coal seam.	IV
MORRISON FORMATION		MORRISON FORMATION (Not recorded)	III
			II
			I

V-C 4 MILES NORTH OF KANE, WYOMING

Formation	Thickness	Lee, 1927	This Report
CLOVERLY FORMATION	75′	Greybull sandstone.	VIII
	↓	Red sandy shale.	VII
			VI
	150′	" " "	V
	50′	Coarse-grained massive sandstone, cross-bedded.	IV
MORRISON FORMATION	↓	Variegated shale.	III
			II
	290′	" " (?)	I

V-D BETWEEN CROOKED AND GYPSUM CREEKS

Formation	Thickness	Moberly, 1960	This Report
SYKES MT. FM.	15′	Thinly interbedded brown siltstone, quartz arenites and gray shale (lowest strata of 136′ total)	VIII
CLOVERLY FORMATION	135′	Variegated claystone	VII
		(Not recorded)	VI
		" "	V
		" "	IV
MORRISON FORMATION			III
			II
		"	I

	VI-A	VI-E	
	“NEAR BRIDGER, M	E MILE CREEK	
	Bauer and Robinson, 1	her, *et al.*, 1946	This Report
55′ to 110′	Sandstone, brown	(Not described)	VIII
— ↓	Mudstone, maroor white with greei purple shale anc of yellow and w sandstone.	(Not described)	VII
— ↓	,, ,,	dstone, dark-gray peb- les of chert and quartz. dstone, dark-gray, iable, poorly sorted, uartz and black chert.	VI
313′	,, ,,	cealed, gray shale. dstone, gray, fine. tone, gray, ashy. cealed.	V?
10′	Black and white c pebble conglom	glomerate, gray to ght-brown, gray and ack chert and quartz- e pebbles.	IV
50′ 129′	Sandstone, buff, fi grained and sof Shale, buff, yellow pink.	cealed. dstone, light-brown. tone, greenish-gray.	III
110′	Sandstone, yellow	dstone, gray-white.	II(?)
		ystone, red-brown. dstone, white soft. ystone, red, vari- blored. dstone, white, light- rown. cealed.	I

CHART VI
PUBLISHED SECTIONS: BRIDGER – PRYOR MOUNTAIN AREA

(See Figure 2 for locations.)

† = General section, no specific locality given.

CHART VI
PUBLISHED SECTIONS:
BRIDGER – PRYOR MOUNTAIN AREA

(See Figure 2 for locations.)

† = General section, no specific locality given.

VI-A "NEAR BRIDGER, MONTANA"

Bauer and Robinson, 1923		This Report
55′ to 110′	Sandstone, brown to gray.	VIII
↓	Mudstone, maroon and white with green and purple shale and lenses of yellow and white sandstone.	VII
↓	" " "	VI
313′	" " "	V
10′	Black and white chert pebble conglomerate.	IV
129′	Sandstone, buff, fine-grained and soft. Shale, buff, yellow and pink.	III(?)
	Sandstone, yellow to tan	II(?)
		I

VI-B RED DOME

	Lee, 1927		This Report
GRYBUL. SS.	12′ to 45′	Sandstone.	VIII
CLOVERLY FORMATION	↓	Shaly beds, highly colored.	VII
CLOVERLY FORMATION			VI
CLOVERLY FORMATION	200′	" " " "	V
CLOVERLY FORMATION	10′ to 45′	Hard, black, chert pebble conglomerate.	IV
MORRISON FORMATION		MORRISON FORMATION (Not described)	III
MORRISON FORMATION			II
MORRISON FORMATION			I

VI-C † NORTHERN CARBON COUNTY, MONTANA

	Knappen and Moulton, 1930		This Report
	60′	Rusty thin-bedded sandstone and sandy shale.	+ VIII
CLOVERLY FORMATION	↓	Bright, variegated clay, volcanic ash and shale.	VII
CLOVERLY FORMATION			VI
CLOVERLY FORMATION	180′	" " " "	V
CLOVERLY FORMATION	45′	Black chert conglomerate and yellow sandstone.	IV
MORRISON FORMATION	↓	Yellow clay and shale and soft sandstone.	III
MORRISON FORMATION	↓	" " " "	II
MORRISON FORMATION	210′	" " " "	I

VI-D † NEAR BOWLER, MONTANA

	Wilson, 1936		This Report
	70′	Thinly bedded brown sandstone.	VIII
CLOVERLY FORMATION	?′	Varicolored clays.	VII
CLOVERLY FORMATION			VI
CLOVERLY FORMATION	?′	" "	V
CLOVERLY FORMATION	50′	Brown and yellow sandstone with abundant black chert pebbles.	IV
MORRISON FORMATION	↓	Varicolored clays with two interbedded yellow to buff sandstones.	III
MORRISON FORMATION	↓	" " "	II(?)
MORRISON FORMATION	200′	" " "	I

VI-E FIVE MILE CREEK

	Gardner, *et al.*, 1946		This Report
		(Not described)	VIII
		(Not described)	VII
KOOTENAI FORMATION	7′ 10′	Sandstone, dark-gray pebbles of chert and quartz. Sandstone, dark-gray, friable, poorly sorted, quartz and black chert	VI
KOOTENAI FORMATION	25′ 1′ 2′ 18′	Concealed, gray shale. Sandstone, gray, fine. Siltstone, gray, ashy. Concealed.	V?
KOOTENAI FORMATION	12′	Conglomerate, gray to light-brown, gray and black chert and quartzite pebbles	IV
MORRISON FORMATION	11′ 8′ 36′	Concealed Sandstone, light-brown Siltstone, greenish-gray	III
MORRISON FORMATION	10′	Sandstone, gray-white.	II(?)
MORRISON FORMATION	[illegible] 1′ 16 [illegible] 11	Claystone, red-brown Sandstone, white soft Claystone, red, varicolored Sandstone, white, light-brown Concealed	I

VII-F ††

SEC. 21, T. 7 S., R. 31 E.,
MONTANA

This Report		Richards, 1955	This Report
VIII		(Not described)	VIII
VII	CLOVERLY FORMATION	" "	VII
VI		" "	VI
V		" "	V
IV(?)		22′ Conglomerate, gray to light-brown, massive, pebbles of sandstone, quartz and chert.	IV
III(?)	MORRISON FORMATION	38′ Siltstone, greenish-gray, clayey, highly calcareous. 14′ Sandstone, white, calcareous. 28′ Siltstone, medium gray. 1′ Limestone, light gray, silty. 92′ Siltstone and shale, gray. 89′ Concealed. 5′ Siltstone and claystone, yellow-brown. 1′ Sandstone, dark gray, calcareous. 15′ Siltstone, claystone, yellow.	III(?)
II			II
I			I

CHART VII
PUBLISHED SECTIONS:
PRYOR – BEAUVAIS CREEK AREA

(See Figure 2 for locations.)

† = General section, no specific locality given.

†† = Section located outside of study area.

CHART VII
PUBLISHED SECTIONS:
PRYOR – BEAUVAIS CREEK AREA
(See Figure 2 for locations.)
† = General section, no specific locality given.
†† = Section located outside of study area.

VII-A † SOUTHERN CROW INDIAN RESERVATION		VII-B PRYOR, MONTANA		VII C 4 MILES SOUTH OF PRYOR, MONTANA		VII D 6 MILES SOUTH OF PRYOR, MONTANA		VII-E †† SEC 22, T. 9 S., R. 34 E. MONTANA		VII-F †† SEC. 21, T. 7 S., R 31 E., MONTANA	
Bauer and Robinson, 1923	This Report	Lee, 1927	This Report	Thom, *et al*, 1935	This Report	Thom, *et al.*, 1935	This Report	Thom, *et al*, 1935	This Report	Richards, 1955	This Report
20′ to 116′ Sandstone.	+ VIII	45′ Sandstone.	VIII	20′ Sandstone, coarse, massive, irregular bedding.	VIII	(Not described)	VIII	12′ Sandstone, shaly, gray with shell fragments.	VIII	(Not described)	VIII
Variegated, purple and green shale with lenses of yellow and white sandstone.	VII	CLOVERLY FORMATION 106′ Colored shaly beds.	VII	CLOVERLY FORMATION 55′ Shale, variegated. 1′ Limestone, white. 50′ Shale, variegated.	VII	CLOVERLY FORMATION " "	VII	23′ Shale, gray. 4′ Shale, pink. 2′ Sandstone, white. 38′ Shale, soft, upper half red and purple, lower half black with 5 feet of hard, white shale in middle. 7′ Shale, hard, white. 6′ Shale, gray, green, purple. 5′ Shale, red, weathers purple.	VII	CLOVERLY FORMATION " "	VII
" " " "	VI	20′ Conglomerate.	VI(?)	20′ Sandstone, light-colored, cross-bedded, grades laterally to conglomerate.	VI	" "	VI		VI	" "	VI
.05′ to 51′ " " " "	V	MORRISON FORMATION (Not described) ↓	V	MORRISON FORMATION (Not described)	V	" "	V	CLOVERLY FORMATION 10′ Shale, soft, light-gray with chalcedony and calcite concretions. 6′ Shale, hard, gray, weathers brilliant white. 1′ Sandstone, hard, worm tracks. 10′ Sandstone, yellow. 5′ Shale, gray. 5′ Sandstone, hard, white. 6′ Shale, gray. 7′ Coal. 12′ Shale, dark-gray. 2′ Shale, dark rusty-brown.	V	" "	V
?′ Conglomeratic sandstone.	IV(?)	↓	IV		IV	15′ Sandstone, conglomerate, weathering dark brown.	IV	13′ Sandstone, dirty gray. 7′ Sandstone, hard, coarse, black mineral grains probably augite or hornblende.	IV(?)	22′ Conglomerate, gray to light-brown, massive, pebbles of sandstone, quartz and chert	IV
Hard, greenish-gray shale, some pink and purple shales, white and yellow sandstones.	III	MORRISON FORMATION ↓	III	MORRISON FORMATION	III	115′ Shale, red or purple.	III(?)	4′ Sandstone, shaly.	III(?)	MORRISON FORMATION 38′ Siltstone, greenish-gray, clayey, highly calcareous 14′ Sandstone, white, calcareous. 28′ Siltstone, medium gray. 1′ Limestone, light gray, silty. 92′ Siltstone and shale, gray. 89′ Concealed. 5′ Siltstone and claystone, yellow-brown. 1′ Sandstone, dark gray, calcareous. 15′ Siltstone, claystone, yellow.	III(?)
" " " "	II	↓	II		II	MORRISON FORMATION 3′ Sandstone, cross-bedded, light colored.	II(?)		II		II
" " " "	I	216′	I		I	23′ Shale, purple-gray. 75′ Shale, pink or red.	I(?)		I		I

Sundance
Worland
Thermopolis
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miles

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